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INSTRUCTOR STATION DISPLAY FOR USE IN T-37 FLIGHT SIMULATION TRAINING

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This study produced the design for an integrated visual display for the instructor/operator station (IOS) of the Advanced Simulator for Pilot Training (ASPT). The study was accomplished in two steps. First, a survey of T-37 instructor pilots (IPs) was conducted to define the information requirements for an ASPT IOS integrated visual display for use in T-37 undergraduate pilot training. A questionnaire was developed and used in the survey. It contained a comprehensive listing of flight information items, and the IP subjects were asked to rate each item in terms of the requirements for use in the display. The questionnaire rating data were statistically analyzed to determine which items

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should be retained for inclusion in the display and which items could be eliminated. In the second step of the study, display symbology was determined for each item retained using MIL-STD-884C and other relevant design specifications, and three integrated display modes of operation were designed. Each display mode design incorporates various display symbols to provide the required display information.

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INTRODUCTION

Background

In 1975, an operational utilization test was conducted to assess the training utility of the Advanced Simulator for Pilot Training (ASPT)[1] in the basic (T-37) phase of undergraduate pilot training (UPT) (Woodruff, Smith, Fuller, & Weyer, 1976). The subject sample used in the test consisted of eight UPT students and seven T-37 instructor pilots (IPs). The students were trained in one of the two T-37 cockpits of the ASPT to a satisfactory level of proficiency in all flight skill areas of training included in the basic phase of UPT. Flight instruction was provided by the IPs from either the right cockpit seat or from the ASPT instructor/operator station (IOS), whichever they preferred. It was observed that the IPs preferred to use the ASPT IOS for flight instruction, although each IP instructed some of the training missions from the right cockpit seat.

One goal of the operational utilization test was to determine if there were any characteristics of the ASPT IOS which needed improvement. To accomplish this, the opinions of the IPs about the design of the IOS were solicited in extensive interviews conducted at the conclusion of the test. Although the results of the interviews were not included in the Woodruff, Smith, Fuller, & Weyer (1976) report, subsequent discussions with the authors and examination of the interview responses indicated that the flight information essential to the evaluation of student performance was difficult to access at the ASPT IOS. This was largely due to an unfamiliar arrangement or layout of flight instruments and the placement of the instruments over a much larger area than they are in the actual T-37 aircraft.

To remedy this, an integrated display was recommended for the ASPT IOS containing only the flight information required to instruct the simulator

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[1]Designated the Advanced Simulator for Undergraduate Pilot Training (ASUPT) when this test was performed.

training missions. The advantages of an integrated display would be a reduction of visual search time to locate the critical flight information, and the elimination of non-essential or secondary displays, instruments, and readouts. In the post-test interviews, however, no determination was made of the information required by the IPs to instruct the UPT training missions, which should be included in the integrated ASPT IOS display. For this reason, the present study was conducted. The objectives of the study were to identify the information requirements for an integrated ASPT IOS flight display, and to determine an optimum format or layout for the display.

ASPT Instructor/Operator Station

The ASPT IOS is located in an area separate from the simulator cockpits, and it is arranged in a semi-wraparound configuration to permit easy access to all panels and their associated controls and displays. The IOS is pictorially illustrated in Figure A-1 (Appendix A). It is comprised of two work stations, a conventional and an advanced station. In the figure, the panel area on the right is the conventional station, and the advanced station is on the left.

The conventional station, shown in Figure A-2 (Appendix A), is comprised of controls and displays that enable the instructor to monitor trainee performance and the simulated aircraft systems, act as ground crew when preparing the simulator for flight, control fuel loading, and set the appropriate environmental conditions prior to each mission. The two large centermost panels on the station are representative of the instrument clusters viewed from the pilot's position in the cockpit. These panels contain the indicators, readouts, and repeater instruments that repeat or reflect the status of the on-board aircraft instruments and controls. Communication controls are provided at this station to allow the instructor to function as a ground controller, tower operator, forward air controller, or general radio operator. Controls are also provided with which the instructor can insert simulator malfunctions, operate the student data recording system, initiate and freeze the simulator, and adjust the in-cockpit closed circuit television (CCTV) camera. Additionally, there are controls that duplicate those at the advanced station, such as the controls for aircraft sound, station lighting, microphone and speaker, and emergency stop.

The advanced station is illustrated in Figure A-3 (Appendix A). It is comprised of four cathode ray tube (CRT) displays (two alphanumeric and two graphic), pushbutton switches for CRT assignment and content control, a control joystick that allows the instructor to "fly" the simulated aircraft, a typewriter keyboard for simulator computer control, and a variety of switches for control of the simulator motion and visual systems, station lighting, aircraft sound, microphone and speaker, and emergency stop. CRT pages can be displayed on any CRT compatible with the type of page (alphanumeric or graphic). The alphanumeric pages generally provide flight data and student scoring. The graphic CRT pages include a cross-country navigation map, several airfields, a tactical range, a target approach and dive angle display, and a bomb circle for surface attack weapons delivery training at a simulated gunnery range (Gila Bend). Hardcopy of any alphanumeric CRT page can be obtained at the advanced station for instructor review and student debriefing.

Three video monitors are provided at the IOS which are positioned across the top. The rightmost is a CCTV monitor that enables the instructor to observe the in-cockpit activities of the student pilot. The center and left video monitors are used to display the visual imagery from two of the seven CRTs that provide the in-cockpit visual scene. These monitors permit the instructor to view the visual scene as it appears to the student in the cockpit.

Integrated Display Technology: A Review of the Literature

Modern CRT technology and microprocessor design have permitted the development of a wide variety of electronic integrated visual displays for aviation applications. The two major benefits of these displays are (a) that they require less space than a complementary set of individual, dedicated instruments, indicators, and readouts and (b) that they facilitate task performance by reducing pilot workload. The most common integrated displays are the vertical situation display (VSD), the horizontal situation display (HSD), and the head-up display (HUD). Other types of electronic integrated displays have been designed for specialized flight training and research applications such as sideways-looking displays, flight path displays, and predictor displays. These displays have been used in both aircraft crew stations and flight simulator instructor stations. The general functions of these displays are described below and a representative example of each display is provided. Additionally, an integrated display designed specifically for instructor station use is presented.

Vertical Situation Display (VSD). The VSD represents a projection of the aircraft situation perpendicular to the pilot's forward line of sight. The basic dimensions provided in a VSD are elevation, azimuth, and rotation. Vertical movement of display elements simulates a change in pitch or vertical flight path. Lateral displacement or movement of display elements signifies a change in heading or horizontal flight path. Rotation of display elements denotes aircraft roll. Because the movement of display elements is in response to aircraft attitude, the first CRT presentations of this type were called Electronic Attitude Director Indicators (EADIs) and that designation continues to be used. Aircraft VSDs are located on the instrument panel, requiring head-down viewing.

A representative VSD is shown in Figure B-1 (Appendix B). It was designed for use in the Drone Control and Data Retrieval System (DCDRS) to enable a console operator to monitor and control Remotely Piloted Vehicles (Hughes Aircraft Company, 1974). The flight information provided in the display includes barometric altitude, radar altitude, true heading, pitch, roll, and true airspeed. Although this information is relatively standard for most VSD designs, other symbologies have been used. For example, the modified Boeing 737 used in the National Aeronautics and Space Administration's (NASA's) terminal configured vehicle (TCV) program has an EADI which also presents glideslope deviation, localizer deviation, a perspective runway, an extended runway centerline, and a potential flight path indicator (Steinmetz, Morello, Knox, & Person, 1976). The VSD designed for the Coordinated Cockpit Display (CCD) at the NASA-Ames Research Center (Baty, 1976) has a turn rate indicator and an instantaneous vertical speed indicator, along with some of the other indicators included in the VSDs for the DCDRS and TCV.

Horizontal Situation Display (HSD). The HSD represents a projection of the aircraft on a horizontal plane beneath the aircraft. Typically, an HSD provides an aircraft symbol superimposed on a map to indicate its geographic position. HSDs are located on the aircraft instrument panel, requiring direct, head-down viewing.

An example of an HSD with a map format is shown in Figure B-2 (Appendix B), which was designed for the CCD. The symbols and indicators in the HSD depict flight path, range altitude, ground and windspeed vectors, desired course, expanded error, navigation aids, waypoints, runway, and obstructions. While most of this display information is standard, HSDs vary in complexity depending on the specific application. For example, the HSD designed for the DCDRS includes a remotely piloted vehicle (RPV) recovery area, surface-to-air missile (SAM) and anti-aircraft artillery (AAA) sites, and estimated time of arrival (ETA) for designated points.

Head-Up Display (HUD). The HUD involves the projection of a display image at a location in the aircraft that is more convenient for pilot viewing during critical phases of flight such as takeoff, landing, and air combat, when it could be disastrous for the pilot to look down inside the cockpit. In most instances, these projected images appear to be at infinity, and are superimposed on the real-world visual scene through the cockpit windscreen. Projected displays are used almost exclusively to present the vertical situation of the aircraft as in the VSD.

The primary use of HUDs has been in military fighter/attack aircraft. An example of HUD symbology is shown in Figure B-3 (Appendix B), which is from the F-14 HUD. It provides an indication of pitch and roll attitude, magnetic heading, vertical velocity, and radar altitude. Although this information is common to most operational HUDs, there are extreme differences in the symbols and formats used between HUD designs. There are many reasons why such a variety of HUD designs have emerged, the most important being that there have been few controlled experiments concerning how HUD design affects pilot performance. Thus, there is scant evidence to suggest that one format or display symbology is superior to any other.

Sideways-Looking Displays. These are situation displays that present a side view of the aircraft. Their basic dimensions are elevation or altitude and range or speed. Sideways-looking displays have limited application, but they can be useful for energy management and for maneuvering close to the limits of the flight performance envelope (Roscoe & Eisele, 1980).

The Side Vertical Situation Display (SVSD) for NASA-Ames Research Center's Coordinated Cockpit Display (CCD) program (Baty, 1976) is shown in Figure B-4 (Appendix B) as an example of a sideways-looking display. The SVSD is intended to provide aircraft altitude and future altitude requirements in a clear and unambiguous format. The display symbols and indicators include an aircraft symbol, altitude tape and digital readout, terrain features, flight path, potential flight path angle scale, instantaneous vertical speed indicator, desired vertical track, waypoints, beacons, and so forth. In the display, the aircraft symbol is fixed at the altitude digital readout box, and it rotates about its midpoint to indicate aircraft altitude.

Flight Path and Predictor Displays. These displays provide a perspective drawing of the path the pilot must follow to stay on course accurately, and they show the predicted path of the aircraft. These displays may include other primary flight data such as airspeed, altitude, pitch attitude, and bank angle in a format comparable to the Vertical Situation Display (VSD). The formats for 10 flight path displays were reviewed by Warner (1979). Two separate categories of displays are presented, those for use in fixed-wing aircraft and those for use in rotary-wing aircraft.

One of the displays designed for use in fixed-wing aircraft is the Path-in-the-Sky display (Knox & Leavitt, 1977), which integrates information about aircraft attitude, kinematic performance, navigation situation, and path prediction into one CRT display. This display is illustrated in Figure B-5 and Figure B-6 (Appendix B). The display symbols associated with the path-tracking situation are an airplane symbol, a vertical projection ("shadow") of the airplane symbol with an extended centerline, a flight path prediction vector, and a programmed path. These symbols are drawn in perspective as though the observer is located above and behind the airplane. The two L-shaped bars in the display provide an Earth-referenced airplane flight path angle, and the bars rotate when the airplane is banked. The potential flight path angle box indicates the acceleration of the airplane relative to the flight path angle bars as a source of thrust and energy management information. The programmed path angle indicator shows the vertical angle of the programmed path. A pilot is tracking correctly when the airplane is flying down the center of the programmed path, with the airplane symbol superimposed over the shadow. The flight path angle bars should be parallel to the programmed path angle indicator.

The perspective display shown in Figure B-7 (Appendix B) was designed for use in rotary-wing aircraft (Murphy, McGee, Palmer, Paulke, & Wempe, 1974). The display provides an indication of altitude error with perspective "poles" and a moving horizon line. A velocity vector and an aiming dot are used to indicate flight path angle and course. The reference height pole indicates absolute altitude, and altitude rate is shown which is similar to a glideslope indicator. Airspeed error is indicated by the distance between the airspeed error indicator and the velocity vector symbol. Digital readouts are included in the display for altitude, airspeed, and distance to go. In this display, the aircraft is on track when the pole track and aiming dot are aligned with the velocity vector symbol.

Instructor Station Integrated Displays. The trend in the design of instructor stations for advanced weapons system simulators has been toward an increased use of CRTs and away from dedicated instruments, indicators, and readouts. The fundamental reason for this emphasis on the use of CRTs is that a multitude of separate display "pages" can be presented on a single CRT, where a page is comprised of all the display information that is presented at one time. With this capability, display information need be presented only when required by the flight instructor to monitor and evaluate student performance and to control the conditions of training during specific flight training exercises. Consequently, less total physical space is required for the instructor's work station, and because an unlimited number of CRT pages may be used, the instructional capability of the station is substantially enhanced. Flight simulators with an instructor station that has one or more CRTs include: (a) the F-15 Instrument Flight Simulator, (b) the A-10 Operational Flight Trainer, (c) the F-5E Instrument Flight Simulator, (d) the F-14 Weapons System Trainer, (e) the EA-6B Weapons System Trainer, (f) the A-6E Night Carrier Landing Trainer, (g) the F-16 Weapons System Trainer, and (h) the F-18 Operational Flight Trainer.

Display integration techniques have been exploited in these flight simulator instructor stations to maximize the quantity of information available on individual CRT pages. An example of an integrated CRT display page is shown in Figure B-8 (Appendix B), which is from the instructor station of the F-15 Instrument Flight Simulator. This station uses three CRTs in a side-by-side horizontal configuration. The display page shown in the figure is presented on the center CRT continuously throughout the training missions. The HUD display area of the page contains F-15 HUD symbology which duplicates the dynamics of the cockpit HUD, enabling the instructor pilot to monitor what the student sees in the simulator cockpit. The X's in the page represent numeric data that show switch positions, indicator lights, and indicator readings in the cockpit; problem time and elapsed time; and malfunctions that were inserted and whether they are active.

Some electronic integrated visual displays may have more than one mode of operation, where individual display modes present information uniquely appropriate to a specific piloting task. The purpose for using separate display modes is to reduce clutter which degrades task performance. The F-14 HUD, for example, has five primary modes and five steering command submodes. The primary modes are takeoff, cruise, air-to-air, air-to-ground, and landing. The submodes are Tactical Air Navigation (TACAN), destination, all weather landing/precision course direction, vector, and manual. The combination of primary modes, submodes, and weapon selection options yields 23 operational HUD modes. These display modes and submodes are selectable by the pilot from a control panel located on the right F-14 instrument/control console. In order for this mode control technique to be effective, however, the display modes and submodes can not be cluttered, and each must provide all the information required by the user to perform the task. Consequently, it is imperative that the users be involved in the display design process to ensure that the displays contain the required information.

Study Approach

The design of any display involves two major steps: (a) the determination of the display information requirements and (b) the identification of display symbols to convey this information and an efficient format for the symbols.

The first step is usually accomplished through a survey of the information required by potential display users and through an analysis of the tasks to be performed with the display. The selection of symbols and the development of a display format in the second step typically involve the application of standardized designs and principles in order to capitalize on "tried and true" display technologies. Display guidelines and design standards are available in the scientific literature for display designers, and they are quite comprehensive in relation to military systems. For example, the Military Standard for Electronically or Optically Generated Displays for Aircraft Control and Combat Cue Information, MIL-STD-884C (1975), establishes general information, symbology, and display format requirements for HUDs, VSDs, HSDs, and so forth. Caution must be exercised in the application of design guidelines and standards, however, because in some cases they are based on expert opinion rather than results of controlled experiments.

The present study was accomplished in two steps. First, a survey of instructor pilots was conducted to define the information requirements for an integrated visual display for the Advanced Simulator for Pilot Training (ASPT) that will have application in T-37 Undergraduate Pilot Training (UPT) and related research and development (R&D). A questionnaire was developed and used in the survey. It contained a comprehensive listing of flight information items, and the pilot subjects were asked to rate each item in terms of the perceived requirement for inclusion in the display. The questionnaire rating data were analyzed to identify which items should be retained for use and which items could be eliminated. In the second step of the study, symbols were determined for each item retained, using MIL-STD-884C and other relevant specifications, and a display format was recommended.

METHOD

Subjects

The subjects were 25 first-assignment T-37 instructor pilots from the 96th Flying Training Squadron of Air Training Command (ATC) at Williams Air Force Base, Arizona. Apart from the T-38 phase of UPT, none of the subjects had prior military flight experience in any aircraft other than the T-37. The number of hours the subjects had instructed student pilots in the T-37 ranged from 15 to 900 hours, with an overall average of 315.4 hours. Table 1 identifies the total hours of flight instruction accomplished by each subject.

Table 1. Subject Flight Instruction Experience

Subject	T-37 Flight Instruction (hours)
1	600
2	300
3	250
4	480
5	750
6	700
7	180
8	500
9	60
10	500
11	40
12	400
13	20
14	100
15	15
16	900
17	200
18	480
19	300
20	60
21	100
22	350
23	150
24	330
25	120

Questionnaire

A questionnaire was used to obtain the pilots' opinions concerning the information required in an integrated instructor station display for monitoring student pilot performance in T-37 simulator flight training. The questionnaire is reproduced in Appendix C. It contains 59 display information items which the subjects were asked to rate for each of five flight categories, using a four-point rating scale. Additional space was provided in the questionnaire for the subjects to add any display items that they would recommend for use in the integrated display.

The list of display items includes most of the flight information that is available to the instructor pilot in the T-37 cockpit, either in the form of instrument indications (e.g., altitude, airspeed, and fuel quantity) or in the form of control settings (e.g., stick position, throttle position, and toe brakes). The list also includes information that is not provided in the cockpit, but might be useful for monitoring student performance (e.g., angle-of-attack and elevator stick force).

The five flight categories for which each of the display information items was rated were adapted from the Syllabus of Instruction for Undergraduate Pilot Training (T-37/T-38) (1979). The syllabus identifies five categories of training: basic, contact, instruments, formation, and navigation. In the questionnaire, the basic and contact training categories were combined, except for the aerobatics procedures in contact training which were considered separately. The rationale for using this approach was so that the specific display requirements for aerobatics instruction could be determined. The remaining three training categories (i.e., instruments, formation, and navigation) were retained without change in the questionnaire.

A booklet was provided with each questionnaire, showing examples of state-of-the-art integrated flight displays. Specifically, it contained illustrations and detailed explanations of the head-up displays (HUDs) used in the F-16, F-15, F-14, A-10, and A-7 aircraft. A display design incorporating both projected and desired flight path information was also included in the booklet. The purpose of these examples was to demonstrate the large amount of flight information that can be compressed into an integrated display through proper engineering design, so that the subjects would not limit their selection of display items due to a lack of familiarity with display symbologies and layouts.

Procedure

The subjects were each given a tour of the Advanced Simulator for Pilot Training (ASPT), followed by a narrated video tape presentation on advanced integrated display designs used in modern military aircraft. Upon completion of the briefing, the subjects were administered the questionnaire. Approximately 1 hour was required for each subject.

The ASPT tour was conducted primarily to acquaint the subjects with the configuration and operation of the instructor station and to identify the potential applications and utility of an integrated instructor station display in pilot training.

The video tape presentation was developed specifically for this R&D effort. It provided a description of the HUDs used in both Air Force and Navy fighter/attack aircraft; namely, the F-16, F-15, A-10, A-7 and F-14. The purpose of the tape presentation was to familiarize the subjects with the symbols and symbol layouts used in specialized integrated displays for military aircraft and with the operation of these displays. In the tape, the portion on the A-7 HUD was animated, showing the dynamics of individual HUD symbols in response to pilot control inputs. For the other HUDs, each display symbol was identified and its function explained. The tape was approximately 20 minutes in length.

The booklet supplied with the questionnaire contained the same material as was covered in the video tape. While completing the questionnaire, the subjects were permitted to refer to the booklet whenever they wanted. A pilot, who was familiar with these HUD designs and the ASPT, supervised each subject session and provided clarification of the purpose and scope of the effort as required.

RESULTS

The results of the investigation are presented in two sections. The first addresses the display information requirements which were determined through the analysis of the questionnaire rating data, and the second section contains the display designs which incorporate the required display information.

Display Requirements

The binomial test (Siegel, 1956) was used in the analysis of the rating data to determine what information items should be included in the integrated display design and what items may be excluded. For the analysis, the frequencies of the REQUIRED and NICE TO HAVE ratings were combined, as were the NOT NEEDED and UNDESIRABLE ratings, for each display information item in each of the five flight categories. The ratings were combined in this manner so that the integrated display would contain the flight information that the pilot subjects considered to be required and/or desirable. Conversely, the display would not include items that were considered to be either unnecessary or undesirable.

In the analysis, the binomial probabilities were determined for the combined frequencies of the REQUIRED and NICE TO HAVE ratings (from 0 to 25) for a given display information item and flight category using the following formula:

$$P(x) = \sum_{i=x}^{N} \binom{N}{i} P^{i} Q^{(N-i)}$$

Where: N = 25, the total number of ratings

x = the number of REQUIRED and NICE TO HAVE ratings

N-i = the number of NOT NEEDED and UNDESIRABLE ratings

P = the expected proportion of REQUIRED and NICE TO HAVE ratings

Q = the expected proportion of NOT NEEDED and UNDESIRABLE ratings

p(x) = the probability of x

The one-tailed probabilities corresponding to several of the combined frequencies were as follows:

Combined Frequency of Ratings	One-Tailed Probability (p)
16	0.1148
17	0.0538
18	0.0216
19	0.0073
20	0.0020
21	0.0005

Since the probability for a frequency of 17 ($p = 0.0538$) exceeded the preselected 0.05 level of significance, the display information items that were rated by 18 or more subjects as REQUIRED or NICE TO HAVE were retained for use in the display, and items that were given these ratings by 17 or less subjects were excluded.

The display information items in each flight category with a combined frequency of 18 or more REQUIRED and NICE TO HAVE ratings are shown in Table 2. Of the 59 information items that were rated, 23 were retained and 36 were eliminated. It is evident from the frequency distributions that the information items were not given consistent ratings across the range of flight categories, but were considered useful for only certain categories. For example, Distance Measuring Equipment (DME) and Command Steering information were recommended for Navigation and Instrument flight, but were judged to be of limited utility for Basic/Contact, Aerobatics, and Formation flight. Table D-1 (Appendix D) contains the combined frequencies for each of the display information items in each flight category.

Display Design

The development of the integrated display designs involved: (a) the selection of display symbols for each of the information items retained for use in the display and (b) the determination of display formats or layouts for the symbols. In the following two sections, the symbols that were selected and the formats that were developed are presented.

Table 2. Combined Frequency of REQUIRED and NICE TO HAVE Ratings for the Display Information Retained

Display Information	Flight Category				
	Basic/ Contact	Aerobatics	Formation	Navigation	Instru- ments
Altitude-Barometric	25	23	24	25	25
Pitch Attitude	24	25	19	24	25
Bank Angle	23	24	22	25	25
Airspeed	25	24	24	25	25
Heading	25			24	25
Vertical Velocity				23	25
G-Load		25	25		
Aircraft Symbol	24	20	18	24	24
Artificial Horizon	24	21	21	24	25
DME				25	25
Course Indicator(CI)				25	25
Radio Magnetic Indicator (RMI)				25	25
Stall	18	24			
Engine RPM		18			18
Landing Gear	20				
Speed Brakes	18				
Flaps	20				
Desired Flight Path				20	21
Glideslope Deviation				22	25
Localizer Deviation				22	25
Fast/Slow				18	21
Command Steering				23	24
Marker Beacons				21	24

Symbol Selection

Display symbols were selected for each of the 23 information items that was retained for use in the integrated display. These symbols were obtained from several sources. To capitalize on display standardization, the symbols prescribed in MIL-STD-884C were used whenever possible. If no corresponding symbology was provided for a specific item of information, symbol selection was based on current display usage. The symbol set that was eventually chosen is identified below, and the display dynamics of each symbol are described.

1. Aircraft Symbol. MIL-STD-884C recommends using the aircraft reference symbology shown in Figure E-1 (Appendix E). This symbol represents an extension of the fuselage reference line. Relative pitch and roll angles of the aircraft are indicated when compared to the manually trimable pitch lines or the artificial horizon.

2. Artificial Horizon, and Pitch and Roll Attitude. Figure E-2 (Appendix E) shows the symbology specified by MIL-STD-884C for the horizon line, pitch attitude, and roll attitude. The horizon line moves dynamically with pitch and roll changes of the aircraft so that it would overlay the horizon as viewed by the pilot in the aircraft cockpit. The pitch ladder extends above and below the horizon line in 5^{0} increments. Solid lines with ends pointed downward toward the horizon line are used to depict pitch-up attitude, and dashed lines with ends pointed upward are used to depict pitch-down attitude. Numeric pitch values are provided by the lines. In addition to moving vertically in the display to portray pitch changes, the horizon line and pitch ladder can rotate in the display as an indication of roll attitude.

3. Bank Angle. A roll reference and pointer should be used as shown in Figure E-3 (Appendix E) to conform to the specifications in MIL-STD-884C. The index should appear across the bottom of the display. The pointer moves to the left and right in conjunction with changes in aircraft roll.

4. Barometric Altitude. The MIL-STD-884C specification for displaying altitude is shown in Figure E-4 (Appendix E). The index line is fixed and the altitude scale slides up and down the vertical line as aircraft altitude changes. Numeric altitude is provided in 500-foot intervals with graduation marks for every 100 feet . The letter at the top of the scale indicates whether it is a barometric (B) or radar (R) reading.

5. Airspeed. Figure E-5 (Appendix E) shows the MIL-STD-884C specification for displaying airspeed. The line or pointer is fixed, and the airspeed scale slides up and down the vertical line as airspeed increases and decreases respectively. Numeric airspeed values are provided at 50-knot intervals with graduation marks for every 10 knots. A command airspeed "karet" may be used as shown to command the pilot to increase airspeed to the indicated value when the karet drops below the index line, and to decrease airspeed when it is above the index line.

6. Heading. The display symbology specified by MIL-STD-884C for heading is depicted in Figure E-6 (Appendix E). The lubber line is fixed and the heading scale slides left and right on the horizontal line. Numeric heading values are used at 10^{o} intervals with graduation marks provided for every 5^{o} of heading. The command heading karet moves to indicate the required heading change.

7. Vertical Velocity. The specification in MIL-STD-884C for displaying vertical velocity can be found in Figure E-7 (Appendix E). The rate of ascent or descent is provided in feet per minute. The displayed information is generally damped to make it usable. Vertical velocity should be displayed digitally to the nearest foot per minute, either above the scale for climb or below the scale for dive when in excess of 2000 feet per minute. When vertical velocity is displayed digitally, the moving pointer should be positioned at the top or bottom of the scale as appropriate. The digital value should not be displayed when climb and dive rates are less than 2000 feet per minute.

8. Command Steering. The display symbology prescribed by MIL-STD-884C for flight director information is presented in Figure E-8 (Appendix E). The pilot steers the aircraft to center the symbol in the display which will place the aircraft on the path to intercept and maintain a preselected computed path through space.

9. Fast/Slow. Speed error should be depicted in accordance with MIL-STD-884C using the symbology in Figure E-9 (Appendix E). This symbol provides an indication of a deviation from a preset airspeed. A vertical bar below the reference line indicates that the speed is low, and that the pilot should increase speed. A vertical bar above the reference line indicates that the speed is high and that the pilot should reduce speed.

10. Glideslope and Localizer Deviation. In MIL-STD-884C, a limits box, as shown in Figure E-10 (Appendix E), is used to represent the Instrument Landing System (ILS) envelope. The box may move horizontally or vertically.

11. Stall. Warning information should be displayed via a large, flashing W or WARN symbol as shown in Figure E-11 (Appendix E) to conform to the requirements in MIL-STD-884C. Although the military standard does not specify the conditions for which the warning symbol should be used, it was judged to have application to all warning situations, including stall.

12. G-Load. Figure E-12 shows the display symbology for presenting acceleration information in g units. The scale is fixed and the pointer moves up and down to indicate the g force. If the scale range is exceeded, positive g force will be digitally displayed at the top of the scale and negative force will appear at the bottom. Digital values are not present unless the scale is exceeded. The military standard does not provide a design specification for indicating g force. The display symbology in Figure E-12 was derived from the vertical velocity symbology.

13. Engine RPM. Percent engine RPM is digitally displayed as presented in Engine E-13 (Appendix E), one readout for the left (L) engine and one for the right (R) engine. Arrows are used next to the readouts to indicate the direction of change. They point upward for increasing RPM and downward for decreasing RPM. This symbology was used in favor of a variety of alternative approaches in order to reduce display clutter.

14. Landing Gear. Figure E-14 (Appendix E) shows the display symbology devised for depicting the status of the landing gear. In the gear-up configuration, UP is displayed and the wheel symbols are pictured in the box.

15. FLAPS. The flap setting is presented digitally as shown in Figure E-15 (Appendix E). This design was used to conserve space.

16. Speed Brakes. The speed brakes can be extended (OUT) or retracted (IN). Figure E-15 (Appendix E) shows how the current state of the speed brakes is presented, either IN or OUT.

17. DME. DME is presented digitally and is located in the upper left of the display as shown in Figure E-16 (Appendix E) where it does not clutter the display.

18. Marker Beacons. The outer (OM) and middle (MM) marker beacon indicators shown in Figure E-16 (Appendix E) consecutively flash as the aircraft flies over the beacons on the approach to landing.

19. Course Indicator (CI). Course information is provided as shown in Figure E-17 (Appendix E). The Course Deviation Indicator (CDI) moves horizontally to indicate course deviation relative to the course selected which is boxed in the upper left-hand area of the display. The heading pointer displays aircraft heading relative to the selected course, and it can rotate 360^{0} about the axis of the large dot at the top end of the CDI. This symbology was used to present the same information as displayed

on the CI in the aircraft, and in a similar configuration. The aircraft CI can also display glideslope and course deviations on ILS approaches, but the limits box shown in Figure E-10 is used for these functions.

20. Radio Magnetic Indicator (RMI). The RMI display symbology in Figure E-18 (Appendix E) includes a digital readout of the VHF Omnidirectional Range (VOR) bearing and a VOR bearing pointer which can rotate 360^{0} around the readout window. This display gives the same bearing information as the aircraft RMI, but it is configured differently to conserve display space.

21. Desired Flight Path. A variety of flight path display designs have been developed which present on a single display the vertical and horizontal situations of the aircraft with respect to a pictorial command flight path. The path is drawn to resemble a highway or pathway in the sky which the pilot must follow to navigate or land the aircraft. Any one of these displays could be used to provide the desired flight path information for the display design in the present study. Two examples of flight path displays were illustrated in Figure B-5 and B-7 (Appendix B). Another example is shown in Appendix E. Two major elements of the display are a three-dimensional perspective channel and an aircraft symbol (Figure E-19a). The aircraft symbol is stationary, and the channel moves horizontally and vertically. The pilot's task is to guide the aircraft symbol through the center of the channel to stay on course accurately. The channel floor and the wings of the aircraft symbol will be parallel and horizontal when the pilot is flying the command path. Horizontal deviation is indicated by the lateral separation between the tail of the aircraft symbol and the centerline of the channel. Vertical deviation is indicated by the vertical separation between the wings on the aircraft symbol and the altitude reference lines. Lines are drawn across the floor of the channel and up the inside walls to provide a speed command indicator. The dashed line eminating from the aircraft symbol is an aircraft path predictor which indicates the future position of the aircraft at 10, 20, 30, and 40 seconds. In addition to the channel and aircraft symbol, other display symbology may be included (Figure E-19b) for either head-down or head-up viewing.

The symbols selected to provide the display information may be color coded to enhance their discriminability. The proper colors to use for display symbols have not been standardized, however. Many color-coding schemes for CRT displays have been developed, but no one set of color-coded symbols has been consistently recommended in preference to another set. MIL-STD-884C indicates that color coding is permissible, although specific color codes are not identified. Since a comprehensive, scientific assessment of alternative color codes for the symbology selected for use in the display design was beyond the scope of the present study, color codes for the symbols will not be provided.

Display Layout

The symbols included in the integrated display design were arranged to conform to the requirements established in MIL-STD-884C, when applicable. These requirements are pictorially illustrated in Figure F-1 (Appendix I). Option B in the figure served as the reference configuration because vertical scales were used to present airspeed and altitude and because bank angle was provided in the display. Since angle-of-attack and turn and slip were not retained for use in the display, the areas reserved for this information in the figure (i.e., AA and SLIP) were assigned substitute symbology. When guidelines concerning the location of display symbols, such as DME, Engine RPM, and flaps were unavailable, current display usage and human factors design principles were used to arrange the display symbols.

Of the 23 symbols retained for use in the display, not all are required simultaneously. For example, glideslope and localizer deviation are required only for ILS approaches, and the radio magnetic indicator is used only for navigating the aircraft. Because the concurrent presentation of all the symbols would unnecessarily clutter the display, several different display modes were designed, each providing symbology corresponding to specific flying tasks. As these tasks are performed, the display mode can be changed through the use of manual instructor station controls so that the appropriate information is always available to the instructor pilot. Multiple display modes will not be beneficial, however, if too many modes are provided so that the instructor is required to switch modes constantly. Consequently, as few modes were used as possible so that the display would not be cluttered with irrelevant symbology.

A total of three operational display modes were designed, as follows:

1. Basic/Aerobatics/Formation Mode
2. Navigation Mode
3. Instruments Mode

The Basic/Aerobatics/Formation Mode was designed to be used for takeoff, aerobatics, formation flight, visual pattern work, and visual landings. The Navigation Mode is for use during point-to-point navigation and training course intercepts. The Instruments Mode was designed for instrument training and ILS landings. At any one time, only one display mode would be presented. Through the use of a manual switch control on the instructor station, the flight instructor would be permitted to switch modes as desired.

The specific flight information contained in each display mode is identified in Table 3. The selection of symbology for each display mode was guided by the display information retained in the flight categories as shown in Table 2. Only the information contained in the list is displayed, and each information item is provided in at least one display mode. A separate display mode was not used for each flight category in order to minimize mode changes during training. In addition, some information is presented in several display modes and, in some cases, all modes because it is needed to monitor the various training missions. Furthermore, some information is used in only one mode to reduce clutter and preclude redundant information. The Basic/Aerobatics/Formation Mode is illustrated in Figure 1, the Navigation Mode in Figure 2, and the Instruments Mode in Figure 3.

Although desired flight path information was retained for use in the integrated instructor station display (see Table 2), no attempt was made to design a flight path display because many designs are currently available. Consequently, one of these may be used such as the flight path display shown in Figure E-19 (Appendix E).

Table 3. Display Mode Symbology

Display Information	Display Mode: Basic/Aerobatics/ Formation	Navigation	Instruments
Altitude-Barometric	X	X	X
Pitch Attitude	X	X	X
Bank Angle	X	X	X
Airspeed	X	X	X
Heading	X	X	X
Vertical Velocity		X	X
G-Load	X		
Aircraft Symbol	X	X	X
Artificial Horizon	X	X	X
DME		X	X
Course Indicator (CI)		X	
Radio Magnetic Indicator (RMI)		X	
Stall	X		X
Engine RPM	X		X
Landing Gear	X		X
Speed Brakes	X		X
Flaps	X		X
Glideslope Deviation			X
Localizer Deviation			X
Fast/Slow			X
Command Steering			X
Marker Beacons			X

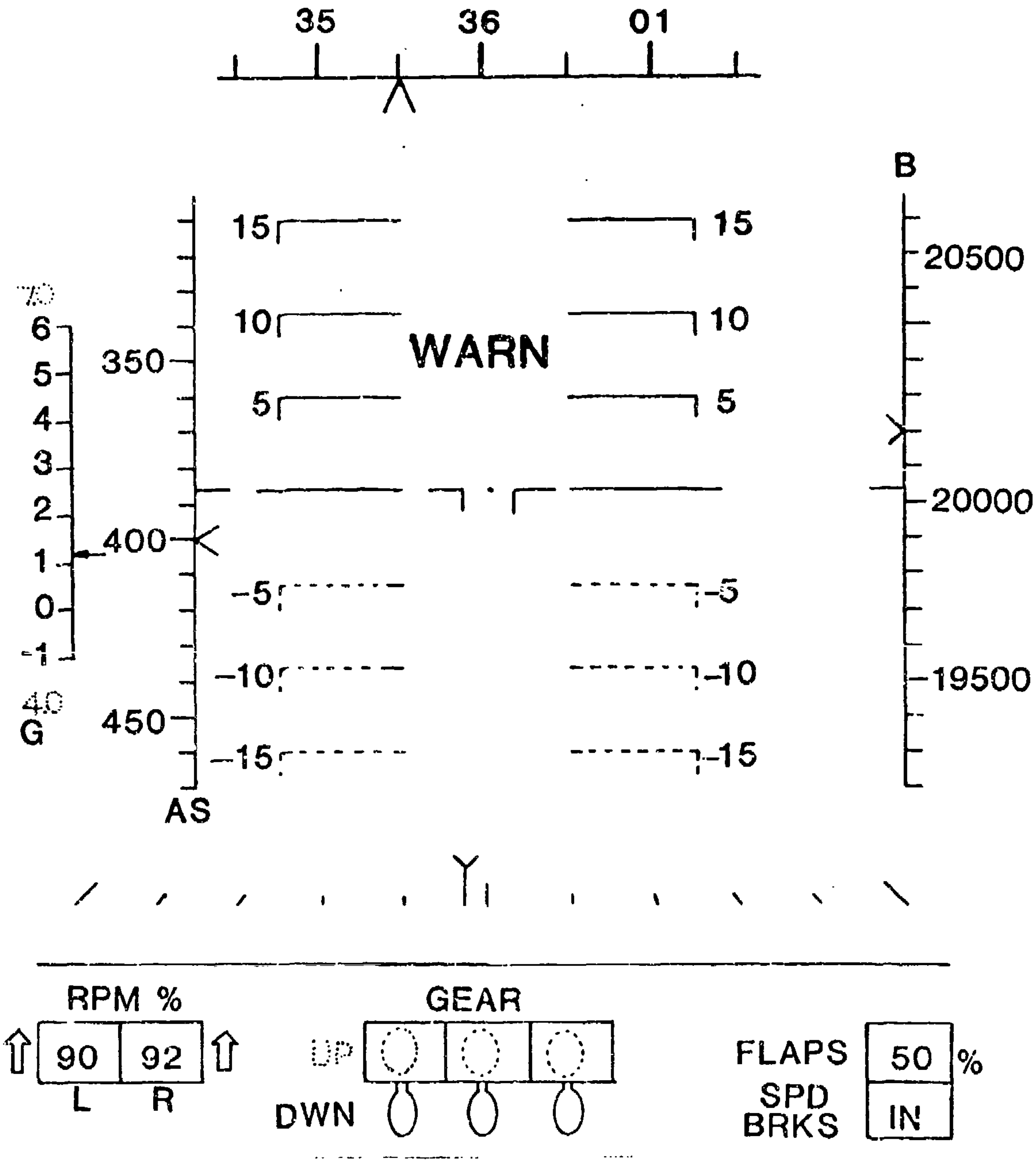


Figure 1. ASPT T-37 Instructor Station Integrated Display-Basic/Aerobatics/Formation Mode.

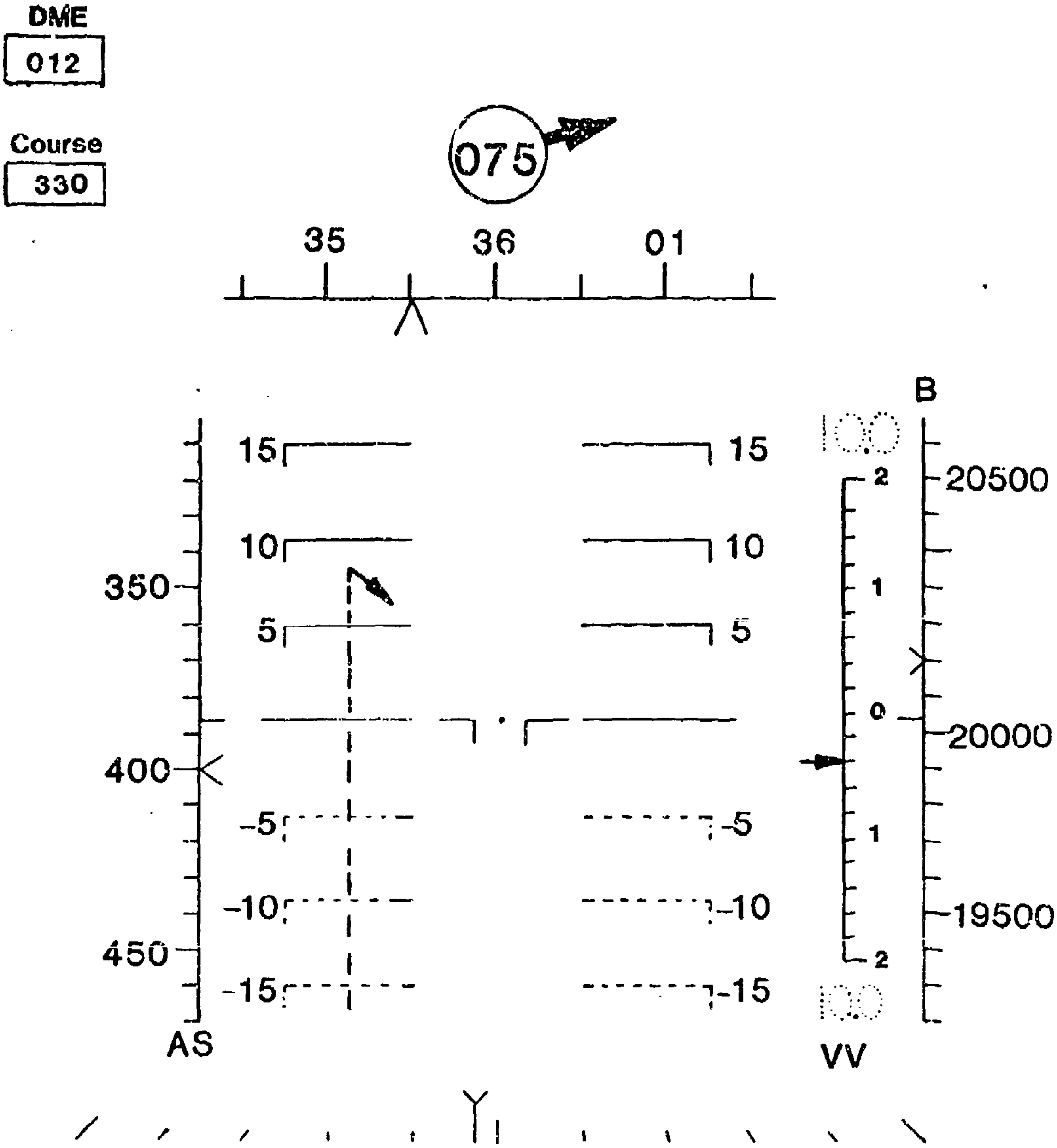


Figure 2. ASPT T-37 Instructor Station Integrated Display-Navigation Mode.

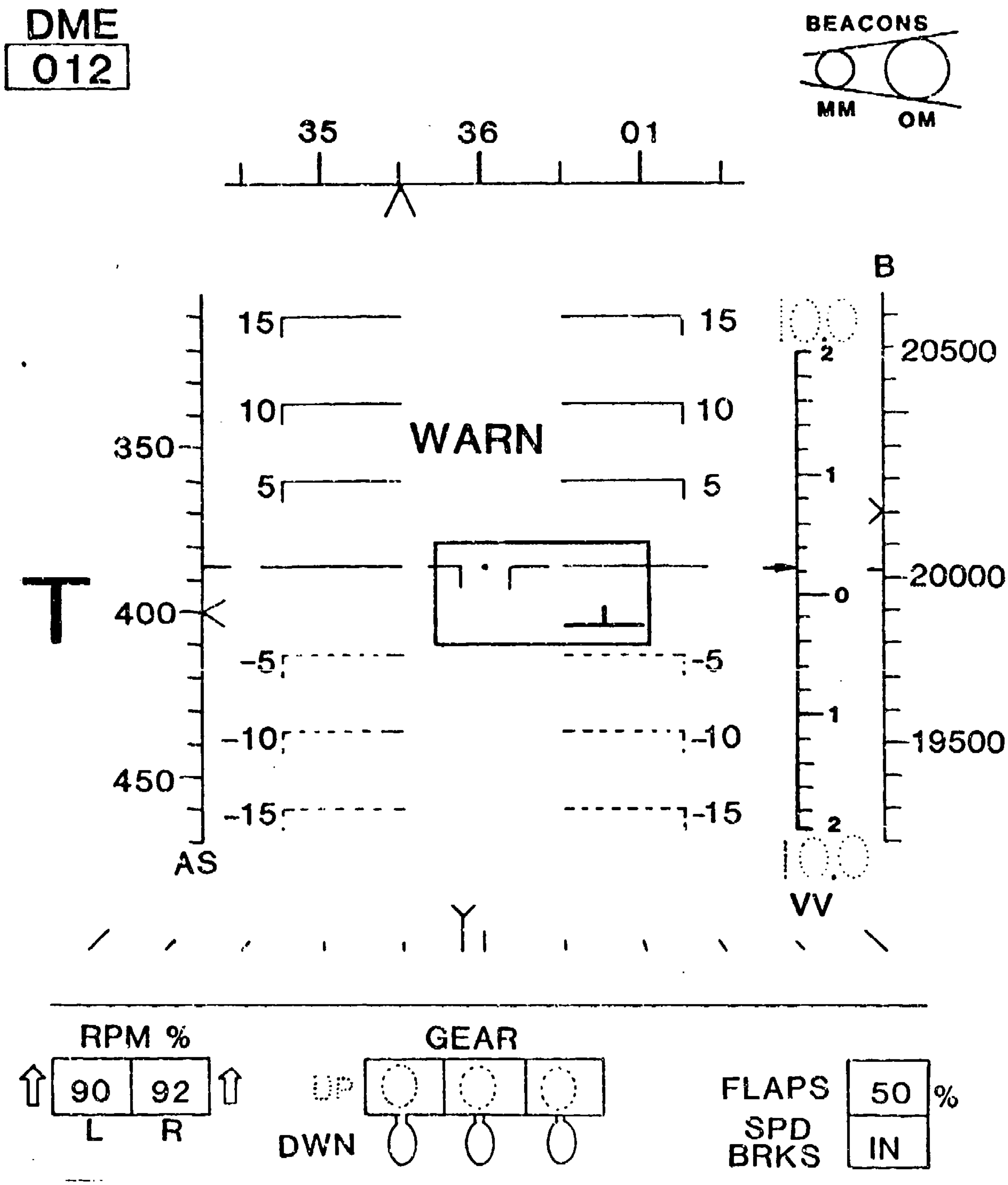


Figure 3. ASPT T-37 Instructor Station Integrated Display-Instruments Mode.

CONCLUSIONS/RECOMMENDATIONS

The integrated display was developed in the present investigation to provide a special purpose flight simulator instructional capability. That is, it was specifically designed for the instructor station of the Advanced Simulator for Pilot Training (ASPT) for use by T-37 instructor pilots in Undergraduate Pilot Training (UPT). Because of this, the results of the study may have limited application to other display design situations.

Design specifications are currently available for select display types, which should be used in preference to the ASPT integrated display design developed herein. For example, MIL-STD-884C identifies the information requirements for a head-up display (HUD), vertical situation display (VSD), and horizontal situation display (HSD). For purposes of comparison, these requirements are presented in Tables 4, 5, and 6 respectively along with weapon system display symbology. The particular symbology to use in these displays is also provided in MIL-STD-884C. This symbology was used in the ASPT integrated display design to achieve maximum display standardization.

In addition to the ASPT instructor station, the integrated display could be used onboard the actual T-37 aircraft by instructor pilots. In the T-37, the instructor and student pilot sit side by side; consequently, each has an unobstructed view out the windscreen. A HUD could be located in front of instructor, comprised of a combining glass on which a collimated display image could be presented. The instructor would be able to see the real-world visual scene through the combining glass and the display image simultaneously. The implementation of a HUD would reduce instructor workload in pilot training and provide a safer training environment because less frequent head-down, in-cockpit instrument cross-checks would be required.

Table 4. HUD Information Requirements (adapted from MIL-STD-884C, 1975)

Information Requirements	HUD Mode				
	Takeoff	NAV	TF/TA	Weapon Delivery	Landing
Heading	X	X#	X#	X#	X
Attitude	X	X#	X#	X#	X
Velocity Vector	X#	X	X	X	X
Director Info	X#	X	X	X	X
Airspeed	X	X#	X#	X#	X
Altitude	X	X#	X#	X#	X
Warning Information	X	X	X	X	X
Angle of Attack Error	X#	X#	X#	X#	X#
Terrain Contour			X		
Breakaway			X	·	X
Range				X	
Closure Rate				X	
Armament Datum Line				X	
Target Designator		X		X	
Ord. Type & No.				X#	
Vertical Velocity	X#			X#	X#
Bomb Fall Line				X	
Opt. Weapon Release				X	
Runway Reference					X
Rotation/Go-Around					X
Roll Reference and Pointer	X	X	X	X	X
Pull-Up Anticipation				X	
Aircraft Reference	X	X#	X#	X#	X
Speed Error	X#	X#	X#	X#	X#
Limits Box				X#	X#
Flight Path Angle and Flight Path Angle Rate (in lieu of Velocity Vector)	X#	X	X	X	X
Angle of Attack	X#	X#	X#	X#	X#

Removable from display with declutter control.

Table 5. VSD Information Requirements (adapted from MIL-STD-884C, 1975)

Information Requirements	VSD Mode				
	Takeoff	NAV	TF/TA	Weapon Delivery	Landing
Heading	X#	X#	X#	X#	X
Attitude	X	X#	X#	X#	X
Velocity Vector	X	X	X	X	X
Director Info	X	X	X	X	X
Airspeed	X	X#	X#	X#	X
Altitude	X	X#	X#	X#	X
Warning Information	X	X	X	X	X
Angle of Attack Error	X	X	X	X	X
Terrain Contour			X		
Breakaway			X	X	X
Range				X	
Closure Rate				X#	
Armament Datum Line				X	
Target Designator		X		X	
Ord. Type & No.				X	
Vertical Velocity	X				X
Bomb Fall Line				X	
Opt. Weapon Release				X	
Runway Reference					X
Rotation/Go-Around					X
Roll Reference and Pointer	X	X	X	X	X
Pull-Up Anticipation				X	
Aircraft Reference	X	X	X	X	X
Speed Error	X#	X#	X#	X#	X#
Limits Box				X#	X#
Flight Path Angle Rate (in lieu of Velocity Vector)	X#	X	X	X	X
Angle of Attack	X#	X#	X#	X#	X#

Removable from display with declutter control.

Table 6. HSD Information Requirements (adapted from MIL-STD-884C, 1975)

Information Requirements	HSD Mode Takeoff	NAV	TF/TA	Weapon Delivery	Landing
Map	X	X	X	X	X
Aircraft Position	X	X	X	X	X
Heading	X	X	X	X	X
Gnd Track	X	X	X	X	X
NAV Steer (Loc)	X	X			X
To/From	X	X			X
Target Points		X		X	
Target Designator		X		X	
Fuel Range	X	X	X	X	X
Data Frame	X	X	X	X	X
Fuel Range Circle	X	X	X	X	X

On the ASPT instructor station, the integrated display image could be made to overlay the out-the-window, cockpit visual scene, which is presented on a CRT monitor, to simulate a virtual-image HUD. Alternatively, a direct-view display could be used in which only the display image is presented on a CRT. The major disadvantage with a direct-view display is that the instructors could not maintain continuous visual contact with the visual scene; they would be required to look away to view the flight display.

Before the ASPT integrated display can be implemented, either on the ASPT instructor station or onboard the actual aircraft, the values to use for various design parameters must be determined. They include:

1. Viewing angle
2. Viewing distance
3. CRT alphanumeric character size
    a. Character height
    b. Character width
    c. Character stroke width
    d. Character spacing
    e. Line spacing
    f. Character font
4. CRT symbols
    a. Symbol size
    b. Symbol separation
5. Display lighting
    a. Luminance
    b. Luminance contrast
    c. Ambient illumination
6. CRT border size
7. Glare
8. Adjacent surfaces
9. CRT flicker
10. CRT phosphor
11. CRT phosphor persistence
12. Screen shape
13. Screen size

14. Distortion
15. Blur
16. Signal-to-noise ratio.
17. CRT response time
18. Display color coding

The display requirements for each of these parameters will be published in a guide for the design of flight simulator instructor station displays. The guide is being prepared concurrently with this paper.

The ASPT integrated display, even with values established for each display parameter, represents a preliminary design or static prototype. Before the display is used to instruct student pilots, it should be evaluated dynamically to determine whether it is optimally configured for actual operating conditions and whether it is an effective instructional aid. One approach to evaluating the display would be to ask a representative sample of display users to view it while a pilot performs a series of flying tasks in the simulator. User opinions concerning the utility of the display for flight instruction would be solicited through a comprehensive questionnaire survey and user interviews. The questionnaire and interviews should address, for example, display visibility, readability, clutter, and dynamics. Another approach to the evaluation of the display would be to ask a group of pilots to instruct a sample of student pilots with the aid of the ASPT integrated display in a variety of flying tasks, and then request the same group of pilots to instruct a second sample of students without the display, using only the instructor station repeater instruments. Pilot opinons about the display and the number of trials required by the students to achieve a criterion level of proficiency could be used as the measures of display effectiveness. The results of the evaluation could be used to identify display modifications and refinements that, when implemented, would improve its instructional utility.

If the evaluation indicates that the ASPT integrated display enhances flight instruction, steps should be taken to ensure that instructor pilots will, in fact, use the display in the instructional process. Most T-37 instructor pilots have had minimal experience with integrated CRT flight displays. While the ASPT display design provides much of the information they use for instruction, it is presented differently than it is on the aircraft instruments. For example, in the ASPT integrated display glideslope and localizer deviation are depicted with a limits box, whereas in the aircraft vertical and horizontal bars on the Course Indicator provide this information. Consequently, unless the instructor pilots are allowed adequate familiarization with the display, they may revert to exclusive use of the instructor station repeater instruments with which they are intimately familiar.

REFERENCES

Baty, D.L. Rationale and description of a coordinated cockpit display for aircraft flight management. Moffett Field, CA: NASA Ames Research Center, Technical Memorandum NASA TM X-3457, November 1976.

Hughes Aircraft Company. Drone Control and Data Retrieval System (DCDRS) preliminary design study final report, Volume III-Trade studies and analyses, Part VII - RCC display/control trade study/analysis report. Dayton, OH:: Aeronautical System Division, Technical Report ASD-TR-74-4, Volume III, Part VII, April 1974.

Knox, C.E., & Leavitt, J. Description of path-in-the-sky contact analog piloting display. Hampton, VA: NASA Langley Research Center, Technical Memorandum NASA TM-74057, October 1977.

Murphy, M.R., McGee, L.A., Palmer, E.A., Paulk, C.H., & Wempe, T.E. Simulator evaluation of three situation and guidance displays for V/STOL zero-zero landings. Moffett Field, CA: NASA Ames Research Center, April 1974.

Roscoe, S.N., & Eisele, J.E. Integrated flight displays. In S.N. Roscoe (Ed.) Aviation Psychology. Ames, IA: Iowa State University Press, 1980.

Siegel, S. Nonparametric statistics for the behaviorial sciences. New York, NY: McGraw-Hill Book Company, 1956.

Steinmetz, G.G., Morello, S.A., Knox, C.E., & Person, L.E., Jr. A piloted-simulation evaluation of two electronic display formats for approach and landing. Hampton, VA: NASA Langley Research Center, Technical Note NASA TN D-8183, April 1976.

U. S. Air Force, Air Training Command. Syllabus of instruction for undergraduate pilot training (T-37/T-38). Randolph Air Force Base, TX: ATC Syllabus P-V4A-A(IFS TEST), June 1979.

U. S. Department of Defense, Aeronautical Systems Division. Electronically or optically generated displays for aircraft control and combat cue information. Wright-Patterson AFB, OH: ASD/ENYESA, Military Standard MIL-STD-884C, April 1975.

Warner, D.A. Flight path displ ys. Dayton, OH: Air Force Flight Dynamics Laboratory, Technical Report AFFDL-TR-79-3075, June 1979.

Woodruff, R.R., Smith, J.F., Fuller, J.R., & Weyer, D.C. Full mission simulation in undergraduate pilot training: An exploratory study. Williams Air Force Base, AZ: Flying Training Division, Air Force Human Resources Laboratory, Technical Report AFHRL-TR-76-84, AD-A039 267, December 1976.

APPENDIX A

Advanced Simulator for Pilot Training Instructor/Operator Station

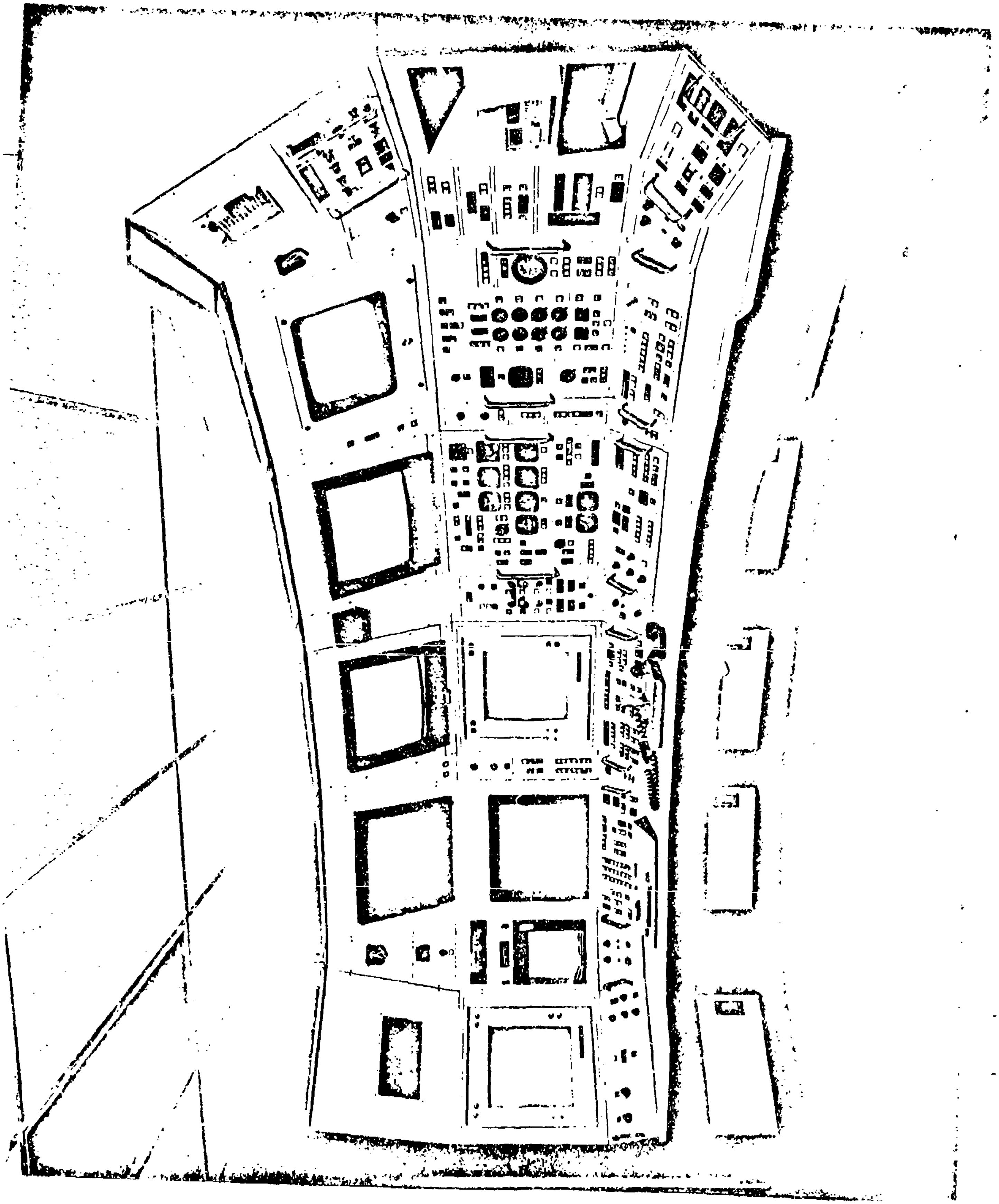


Figure A-1. ASPT advanced/conventional IOS.

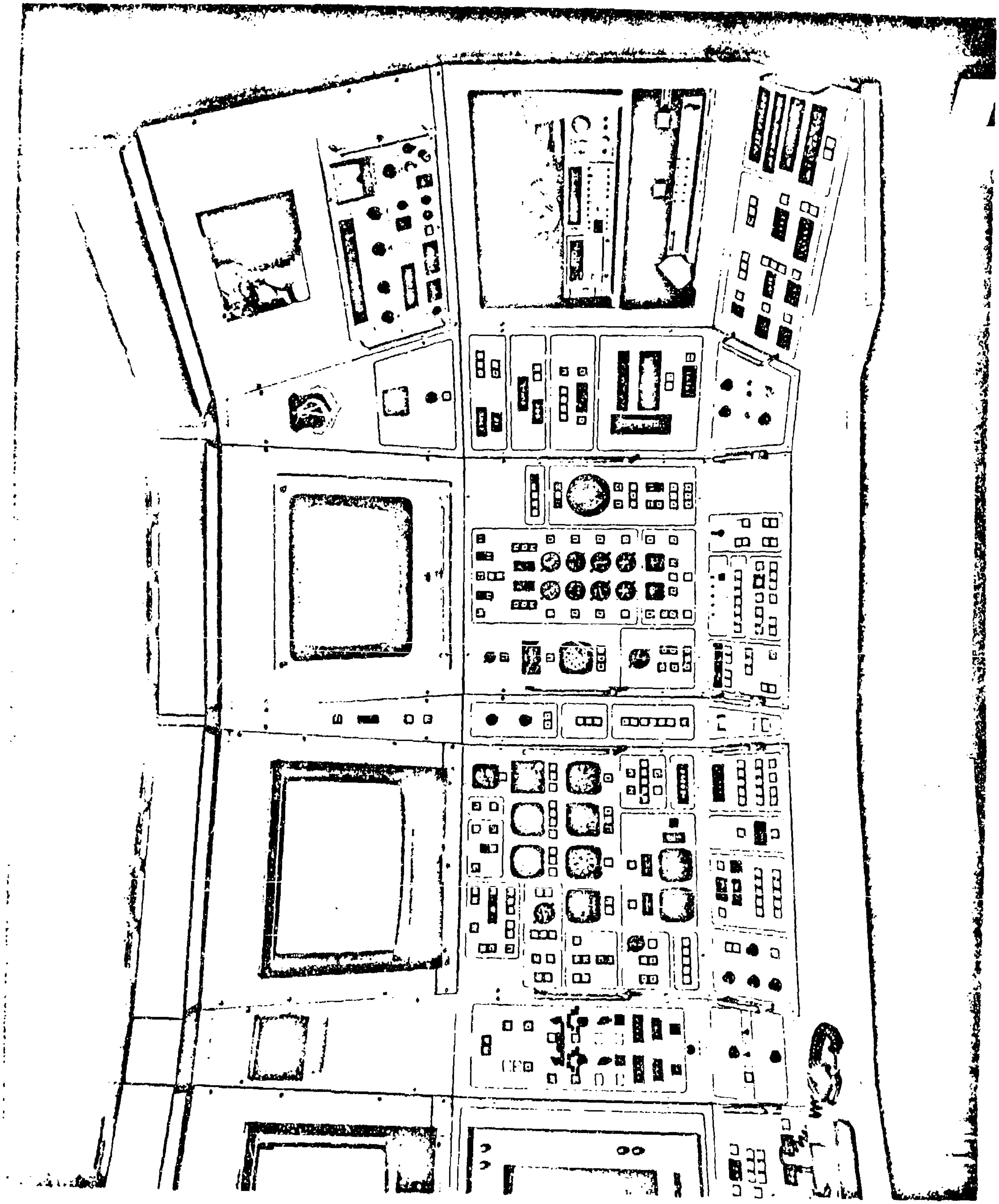


Figure A-2. ASPT conventional IOS.

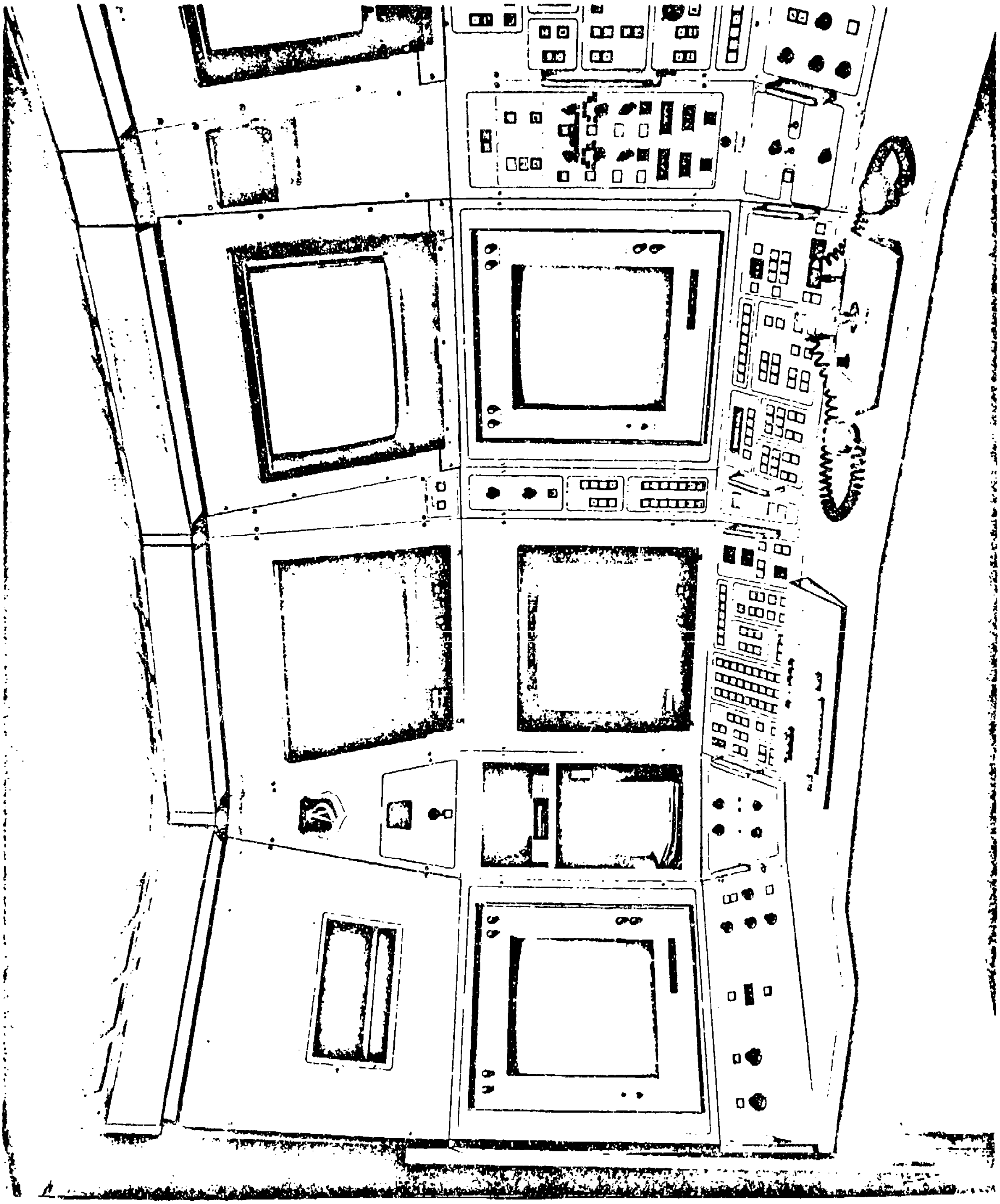


Figure A-3. ASFT advanced IOS.

APPENDIX B

Electronic Integrated Visual Displays

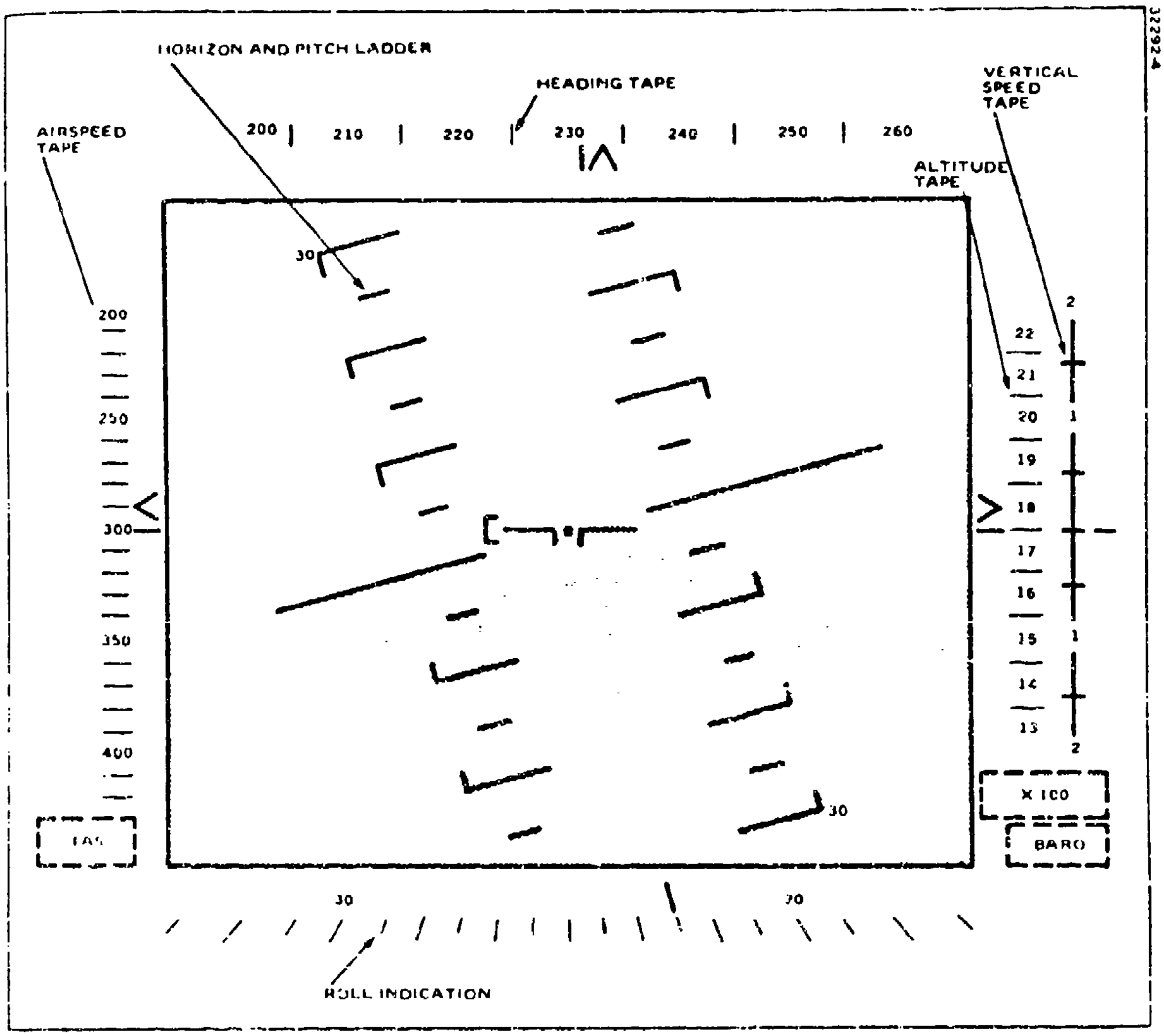


Figure B-1. Vertical situation display (from Hughes Aircraft Company, 1974).

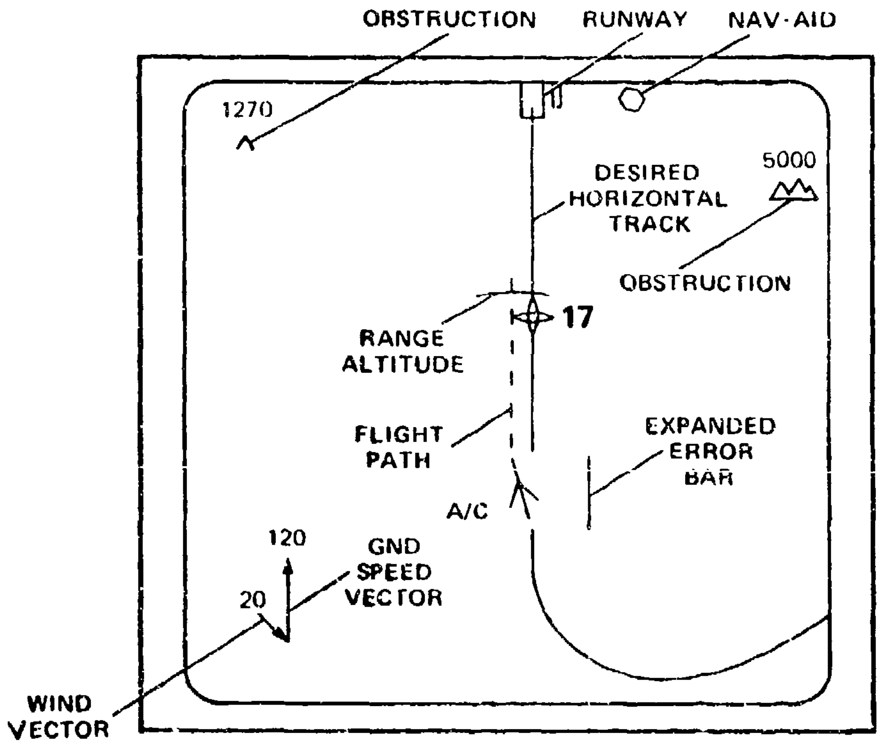


Figure B-2. Horizontal situation display (from Baty, 1976).

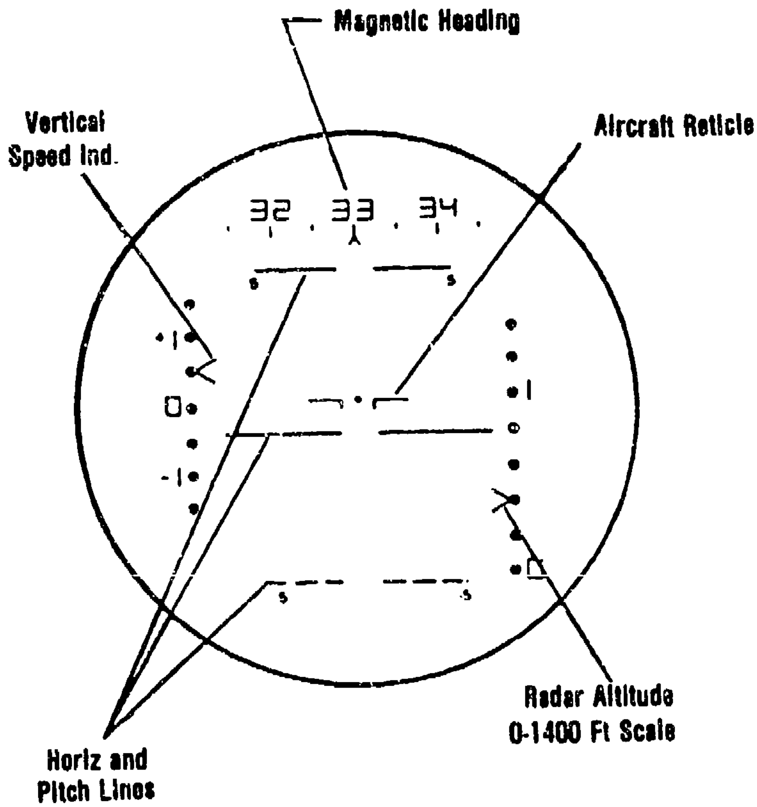


Figure B-3. F-14 Head-Up Display.

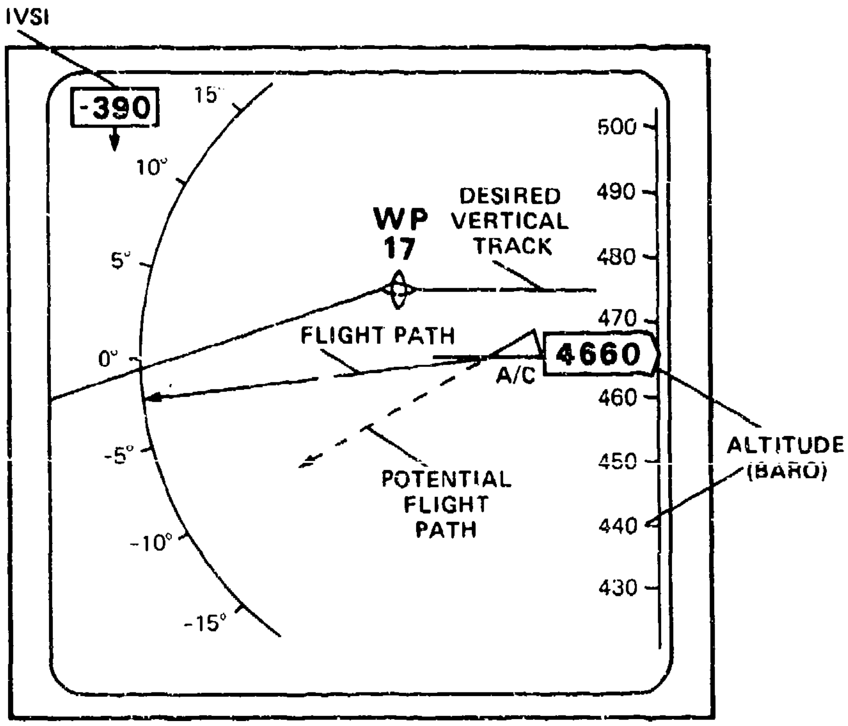


Figure B-4. Side vertical situation display (from Baty, 1976).

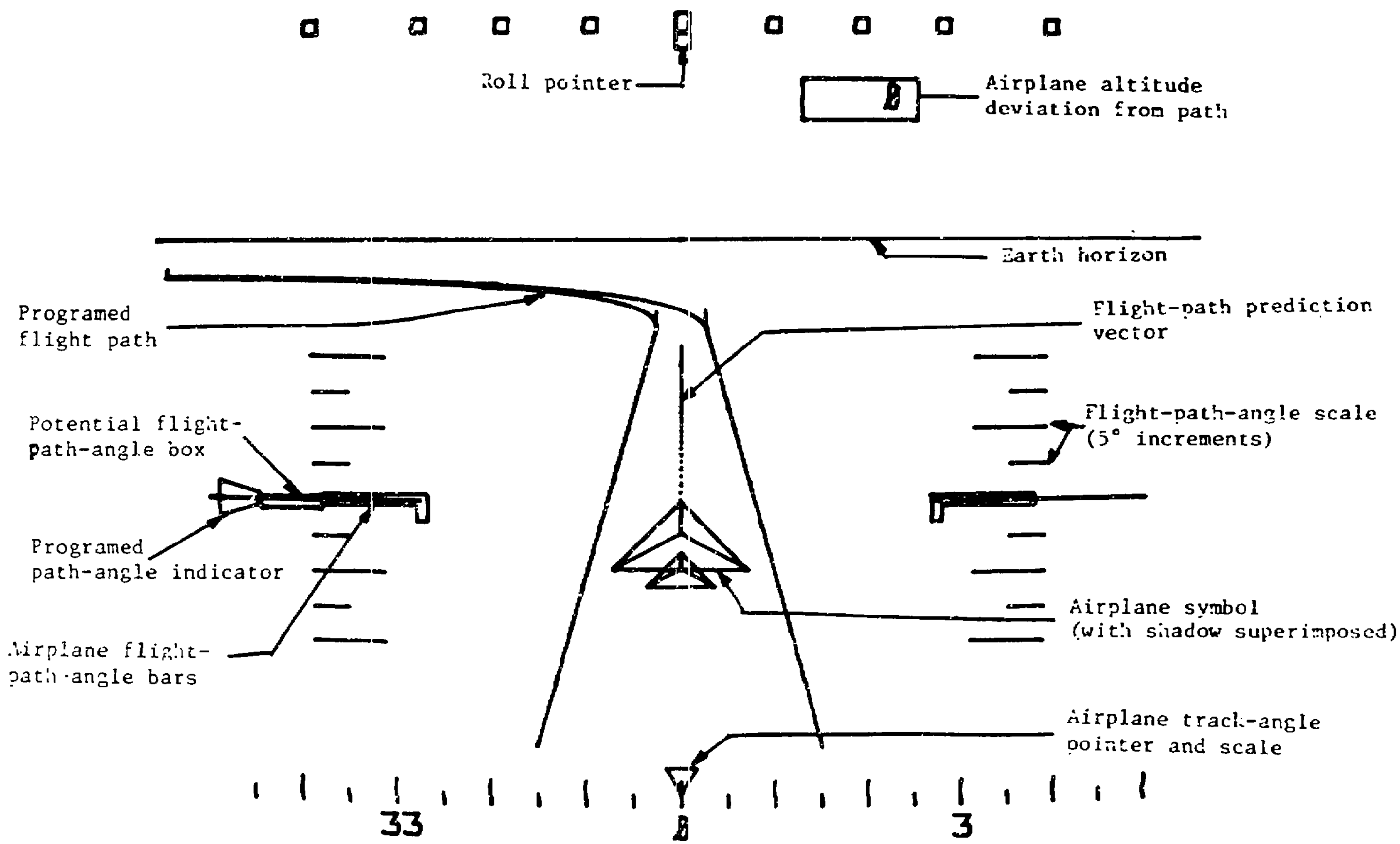


Figure B-5. The Path-in-the-Sky contact analog display (from Knox and Leavitt, 1977).

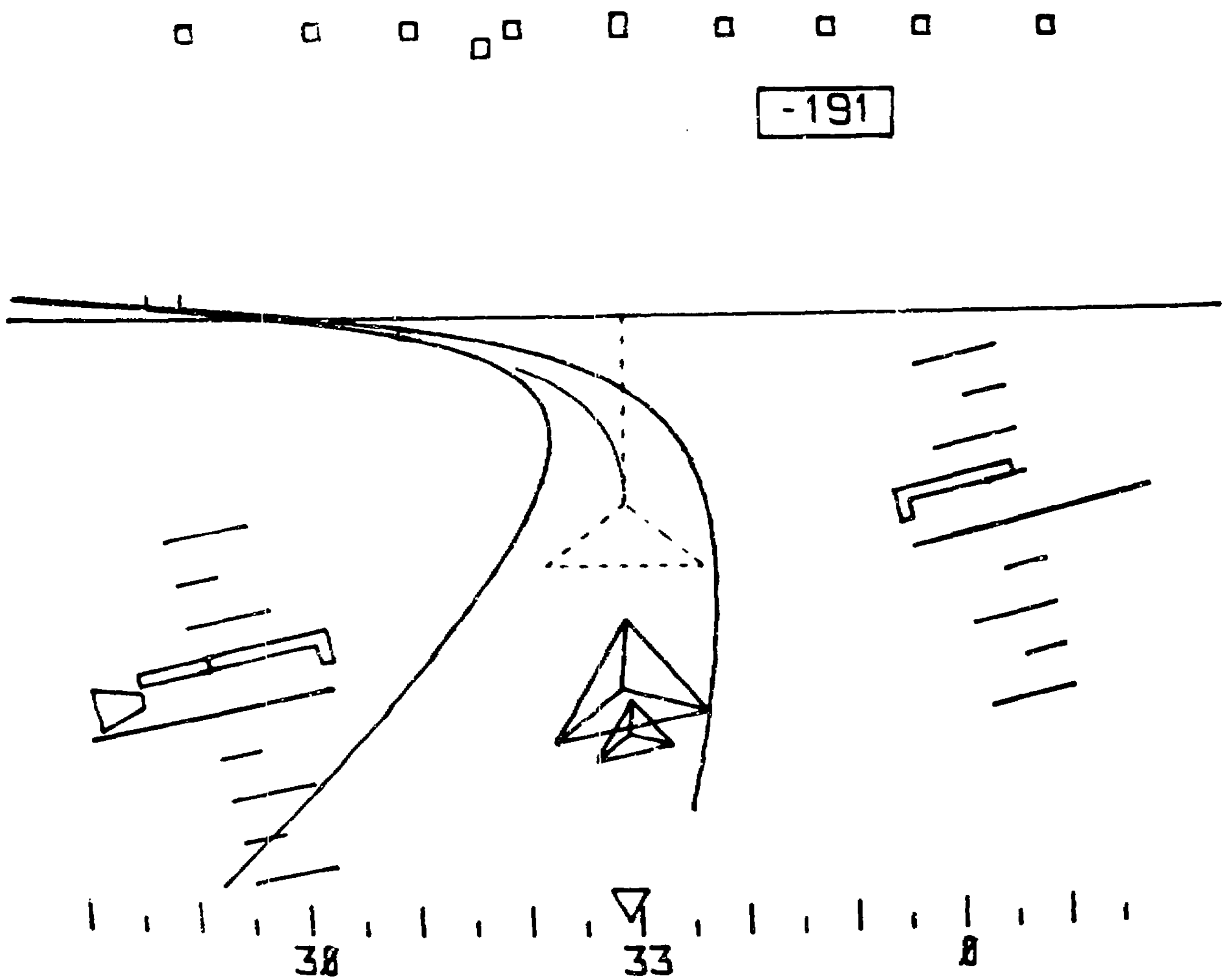


Figure B-6. The Path-in-the-Sky display showing the aircraft below the flight path and climbing in a left bank of 13° (from Knox and Leavitt, 1977).

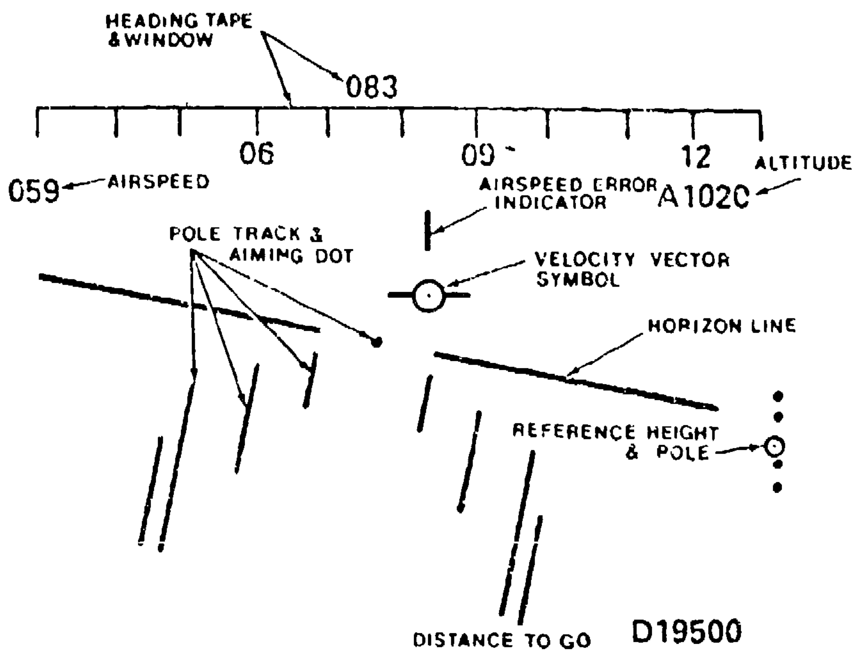
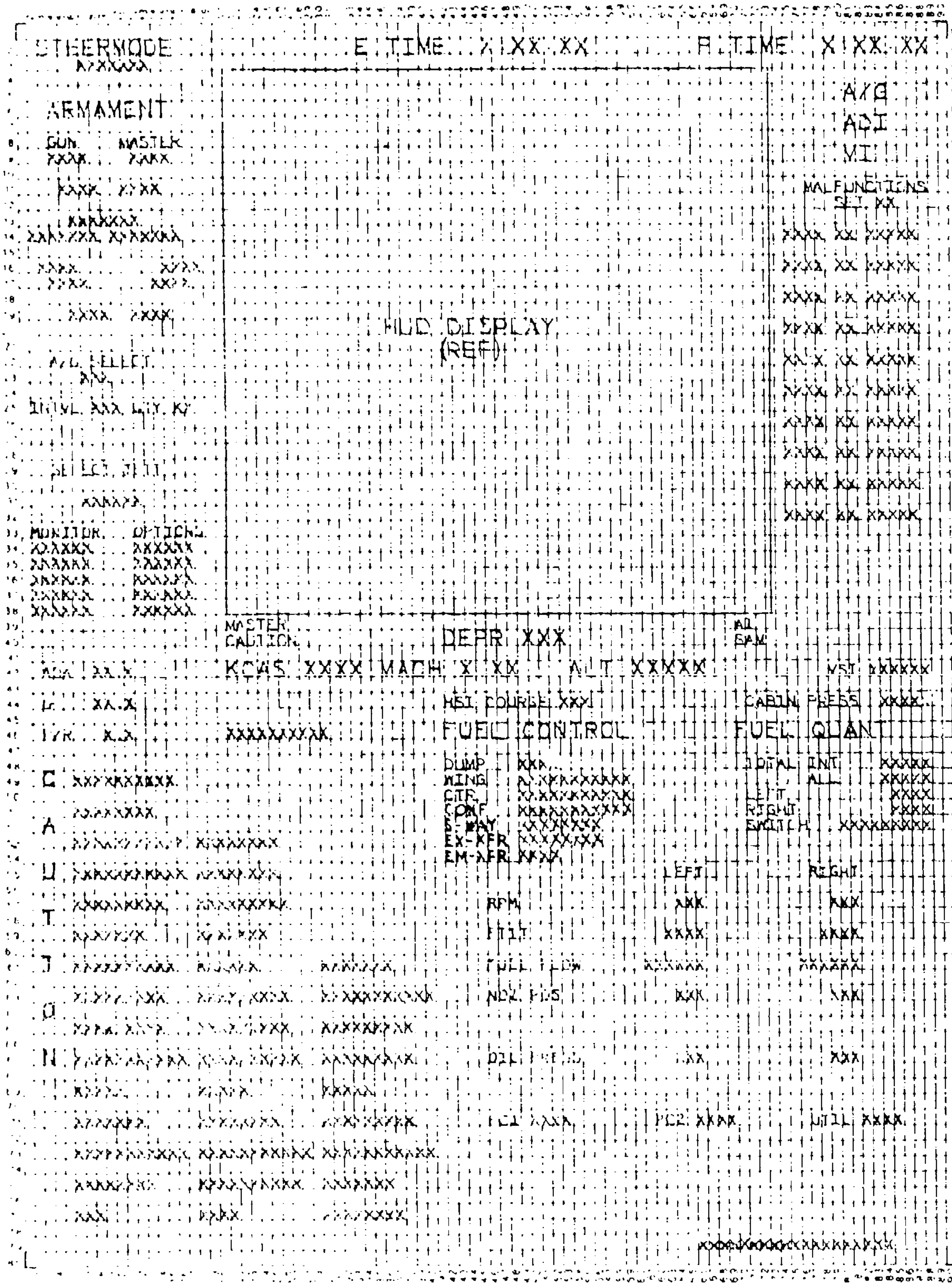


Figure B-7. SAAB Perspective Display (from M.R. Murphy, L.A. McGee, E.A. Palmer, C.H. Paulk and T.E. Wempe, 1974).



INCREASED INTERNAL FUEL CONFIGURATION DISPLAY

Figure B-8. F-15 Instrument Flight Simulator CRT Display Page.

APPENDIX C

Pilot Questionnaire

QUESTIONNAIRE

ASPT INSTRUCTOR STATION INTEGRATED DISPLAY REQUIREMENTS

Objective

The objective of this research is to develop an integrated dynamic visual display for the instructor station of the Advanced Simulator for Pilot Training (ASPT) which is operated and maintained by the Operations Training Division of the Air Force Human Resources Laboratory (AFHRL/OT) at Williams AFB. This display is being developed for T-37 instructor pilot use during T-37 flight training and research in the ASPT. The display will consist of computer generated symbols, similar to a head-up display (HUD), which will be presented on a cathode ray tube (CRT). The display symbology will provide the flight information recommended by the instructor pilots who participated in this study. The display will be dynamic in the sense that the flight information will be continuously updated.

Instructions

In the following pages, rate each display information item under all five flight categories in terms of applicability in an integrated display for instructor pilot use during T-37 training. The definitions of the ratings are provided below. More display information items have been listed than are actually found in the T-37, such as angle of attack and aircraft aimpoint. The reason for this was to determine whether these display items would be useful for T-37 flight instruction even though they are not available to the instructor pilot in the cockpit. If you feel there is any additional information that should be included in the display not appearing on the list, please identify this information using the blank spaces on the last page of the questionnaire and give it the appropriate rating (i.e., 1 or 2).

Rating Scale Definitions

1. REQUIRED: Display information is required for instruction in flight category.

2. NICE TO HAVE: Display information is not required, but would facilitate instruction in flight category.

3. NOT NEEDED: Display information would not facilitate instruction in flight category.

4. UNDESIRABLE: Display information would interfere with instruction in flight category. Effect on instruction would be negative, possibly because unneeded information would clutter the display.

DISPLAY INFORMATION	FLIGHT CATEGORY																			
	Basic/Contact				Aerobatics				Formation				Navigation				Instrument			
Flight Instruments																				
Altitude-Barometric	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Altitude-Radar	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Pitch Attitude	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Bank Angle	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Airspeed	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Heading	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Vertical Velocity	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Mach	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
G-Load	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Angle of Attack	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Aircraft Symbol	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Artificial Horizon	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
DME	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Turn Rate	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Course Indicator (CI)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Radio Magnetic Indicator (RMI)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Stall	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Barometric Pressure	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Predictor Information																				
Aircraft Aimpoint (Velocity Vector)	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Desired Flight Path	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4

DISPLAY INFORMATION	FLIGHT CATEGORY				
	Basic/Contact	Aerobatics	Formation	Navigation	Instrument
GCA/ILS					
Glideslope Deviation	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Localizer Deviation	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Fast/Slow	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Command Steering	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Marker Beacons	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
COMM/NAV					
IFF Transponder	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
UHF Frequency	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
VHF NAV Frequency	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
System Status					
Exterior Lights	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Interior Lights	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Cockpit Oxygen	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Cabin Temperature	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Hydraulic Pressure	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Electrical Load/Batt	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Pitot Heat	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Boost Pump	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Canopy Locked	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Emergency					
Master Caution	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Caution/Warning	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Circuit Breakers	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4

DISPLAY INFORMATION	FLIGHT CATEGORY																			
	Basic/Contact				Aerobatics				Formation				Navigation				Instrument			
Pilot Control																				
Stick Position	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Rudder Position	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Trim Pressure	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Throttle Position	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Aileron Stick Force	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Elevator Stick Force	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Engines/Fuel																				
Engine RPM	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Exhaust Gas Temp	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Fuel Flow	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Oil Pressure	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Fuel Quantity	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Landing/Taxi																				
Landing Gear	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Speed Brakes	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Spoiler	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Flaps	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Touchdown	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Thrust Attenuators	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Nose Wheel Steering	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Toe Brakes	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4

DISPLAY INFORMATION	FLIGHT CATEGORY				
	Basic/Contact	Aerobatics	Formation	Navigation	Instrument
Other Display Information					
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2
______	1 2	1 2	1 2	1 2	1 2

APPENDIX D

Combined Frequencies of REQUIRED and NICE TO HAVE Ratings

Table D-1. Frequency of Pilots Selecting REQUIRED and NICE TO HAVE Ratings for Each Display Information Item by Flight Category

Display Information	Flight Category: Basic/ Contact	Aerobatics	Formation	Navigation	Instru- ments
Altitude-Barometric	25*	23*	24*	25*	25*
Altitude-Radar	4	6	4	15	16
Pitch Attitude	24*	25*	19*	24*	25*
Bank Angle	23*	24*	22*	25*	25*
Airspeed	25*	24*	24*	25*	25*
Heading	25*	17	16	24*	25*
Vertical Velocity	19*	6	11	23*	25*
Mach	0	3	4	9	7
G-Load	7	25*	25*	3	4
Angle of Attack	10	16	7	4	7
Aircraft Symbol	24*	20*	18*	24*	24*
Artificial Horizon	24*	21*	21*	24*	24*
DME	7	6	8	25*	25*
Turn Rate	2	3	3	12	15
Course Indicator (CI)	6	2	3	25*	25*
Radio Magnetic Indicator (RMI)	7	3	4	25*	25*
Stall	18*	24*	17	8	9
Barometric Pressure	6	2	2	14	14
Engine RPM	17	18*	17	17	18*
Exhaust Gas Temperature	9	8	8	7	8
Fuel Flow	5	4	5	12	9
Oil Pressure	5	5	6	5	5
Fuel Quantity	9	9	12	14	13
Landing Gear	20*	13	15	15	17
Speed Brakes	18*	12	15	11	15
Spoiler	9	7	5	4	4
Flaps	20*	12	14	15	17
Touchdown Indicator	12	7	8	10	10
Thrust Attenuators	11	5	8	4	4
Nose Wheel Steering	11	5	4	3	3
Toe Brakes	11	6	4	3	3
Aircraft Aimpoint (Velocity Vector)	17	15	17	15	17
Desired Flight Path	14	13	10	20*	21*
Glideslope Deviation	5	0	5	22*	25*
Localizer Deviation	5	0	5	22*	25*
Fast/Slow	10	8	7	18*	21*
Command Steering	3	0	4	23*	24*
Marker Beacons	3	1	4	21*	24*
IFF Transponder	4	3	4	14	13
UHF Frequency	8	5	7	15	15
VHF NAV Frequency	4	2	3	16	16

TABLE D-1. (cont'd) Frequency of Pilots Selecting REQUIRED and NICE TO HAVE Ratings for Each Display Information Item by Flight Category

Display Information	Flight Category: Basic/ Contact	Aerobatics	Formation	Navigation	Instru- ments
Exterior Lights	5	3	4	8	10
Interior Lights	4	3	2	6	6
Cockpit Oxygen	10	7	6	9	7
Cabin Temperature	3	1	1	2	1
Hydraulic Pressure	12	10	8	9	10
Electrical Load/Battery	11	9	8	11	11
Pitot Heat	5	4	4	13	14
Boost Pump	8	8	5	5	5
Canopy Locked	11	5	4	4	4
Master Caution	17	16	17	16	15
Caution/Warning	14	12	13	14	14
Circuit Breakers	4	3	3	5	4
Stick Position	10	14	9	3	5
Rudder Position	8	10	8	3	5
Trim Pressure	15	13	14	12	14
Throttle Position	14	13	14	11	9
Aileron Stick Force	11	11	12	8	9
Elevator Stick Force	15	14	15	10	11

* $\underline{p} \leq 0.0216$

APPENDIX E

Integrated Display Symbology

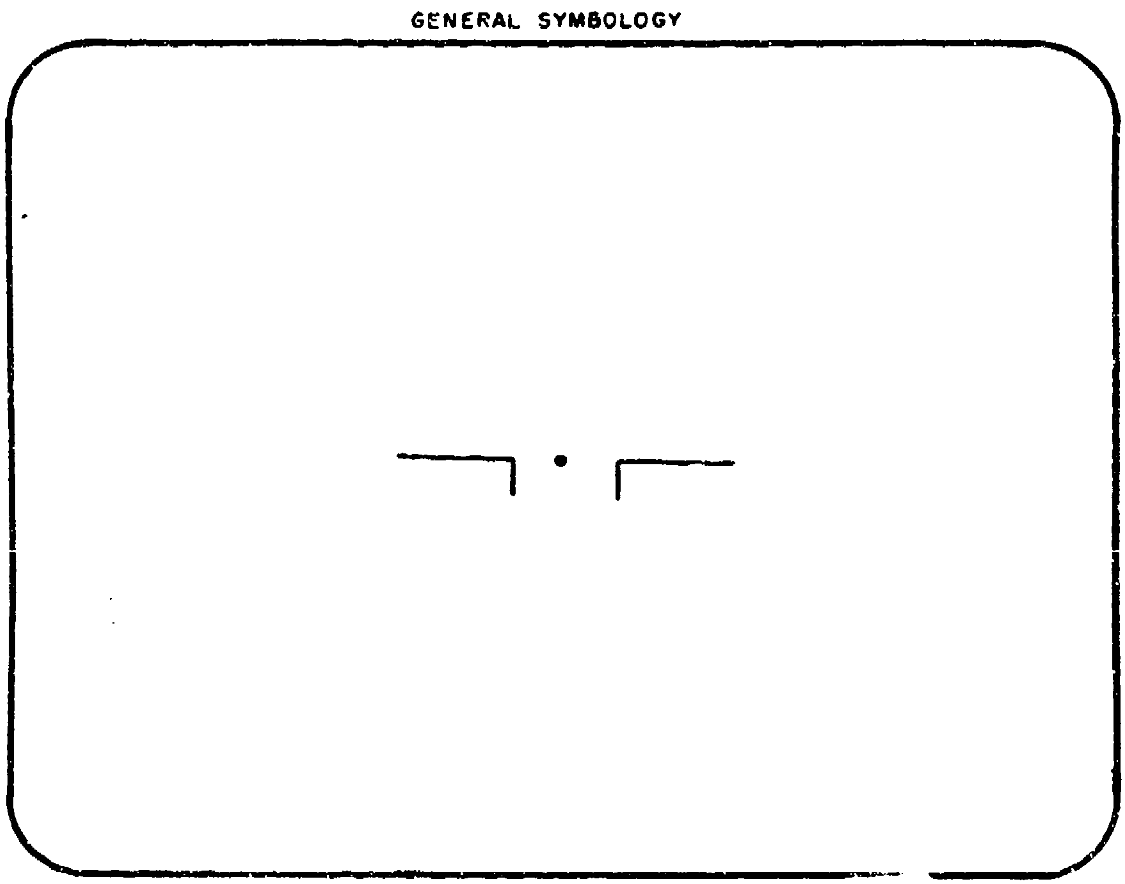
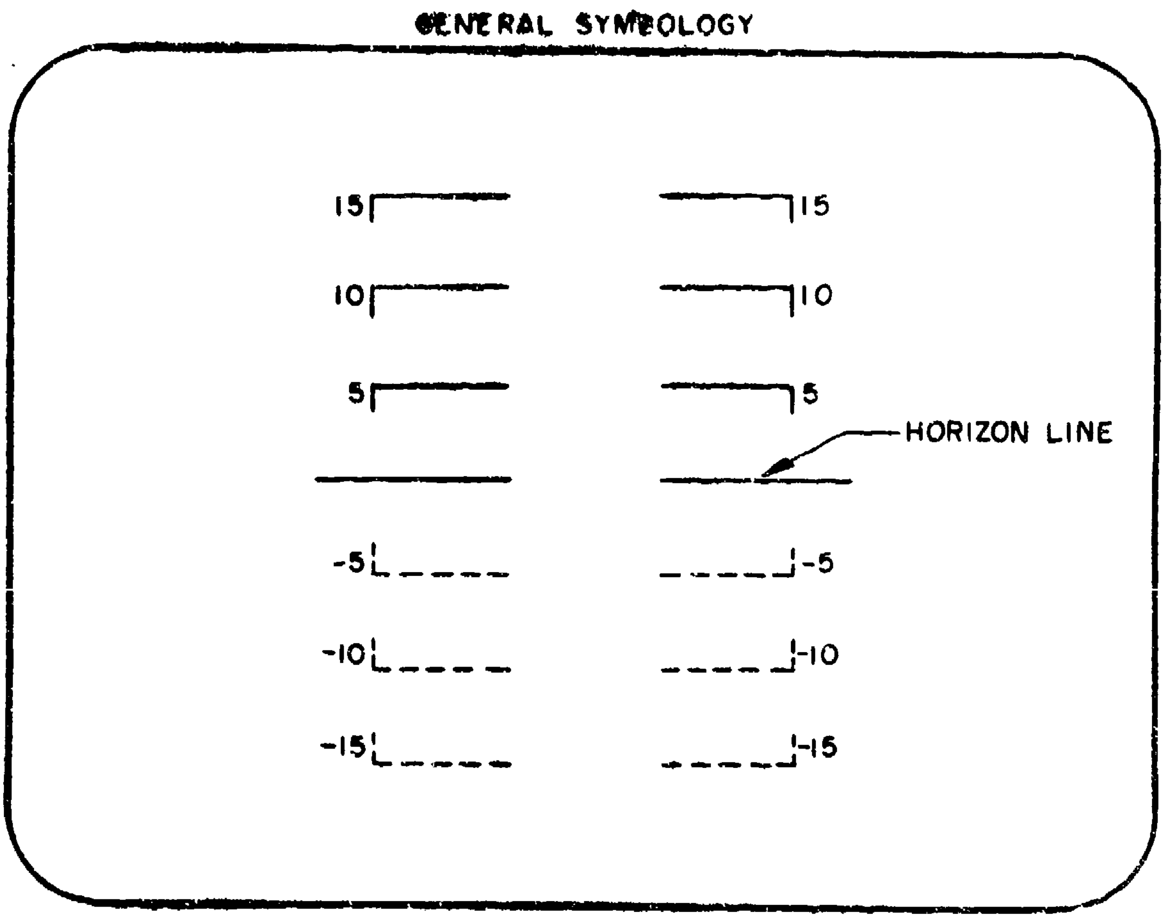


Figure E-1. Fixed aircraft reference (from MIL-STD-884C, 1975).



Note: Display shown is compressed. Actual usage would be 1:1 Real World relationship particularily between ±30°.

Figure E-2. Horizon line and pitch attitude scale (from MIL-STD-884C, 1975).

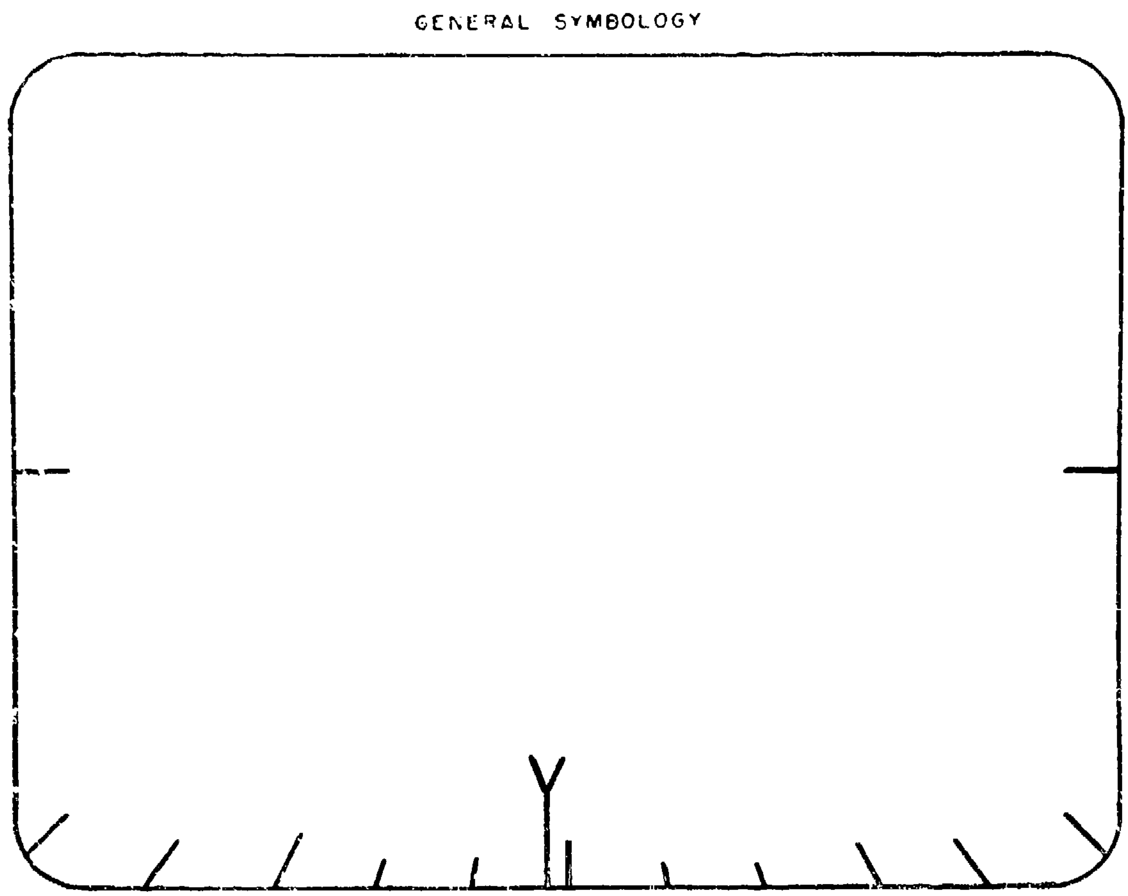


Figure E-3. Roll reference and pointer (from MIL-STD-884C,1975).

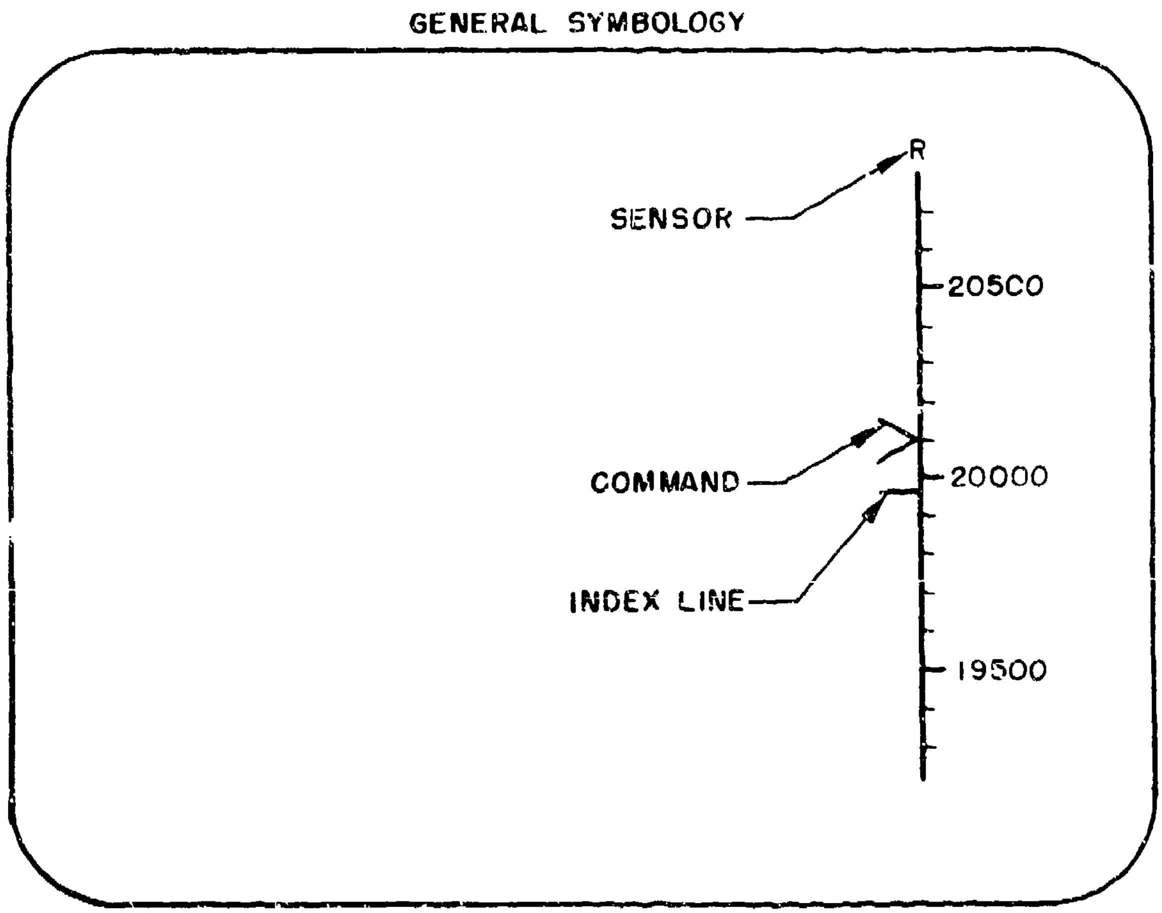


Figure E-4. Radar or barometric altitude (from MIL-STD-884C, 1975).

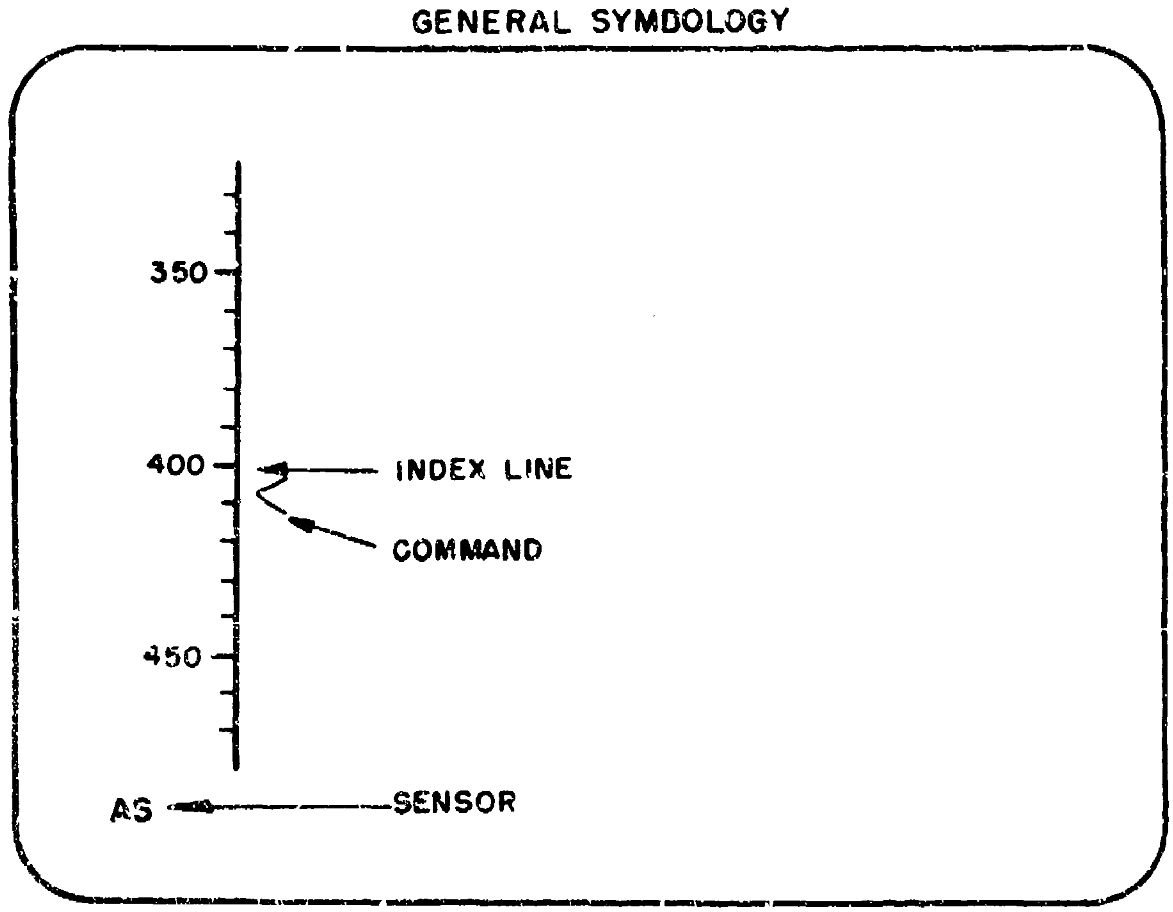


Figure F-5. Airspeed (from MIL-STD-884C, 1975).

GENERAL SYMBOLOGY

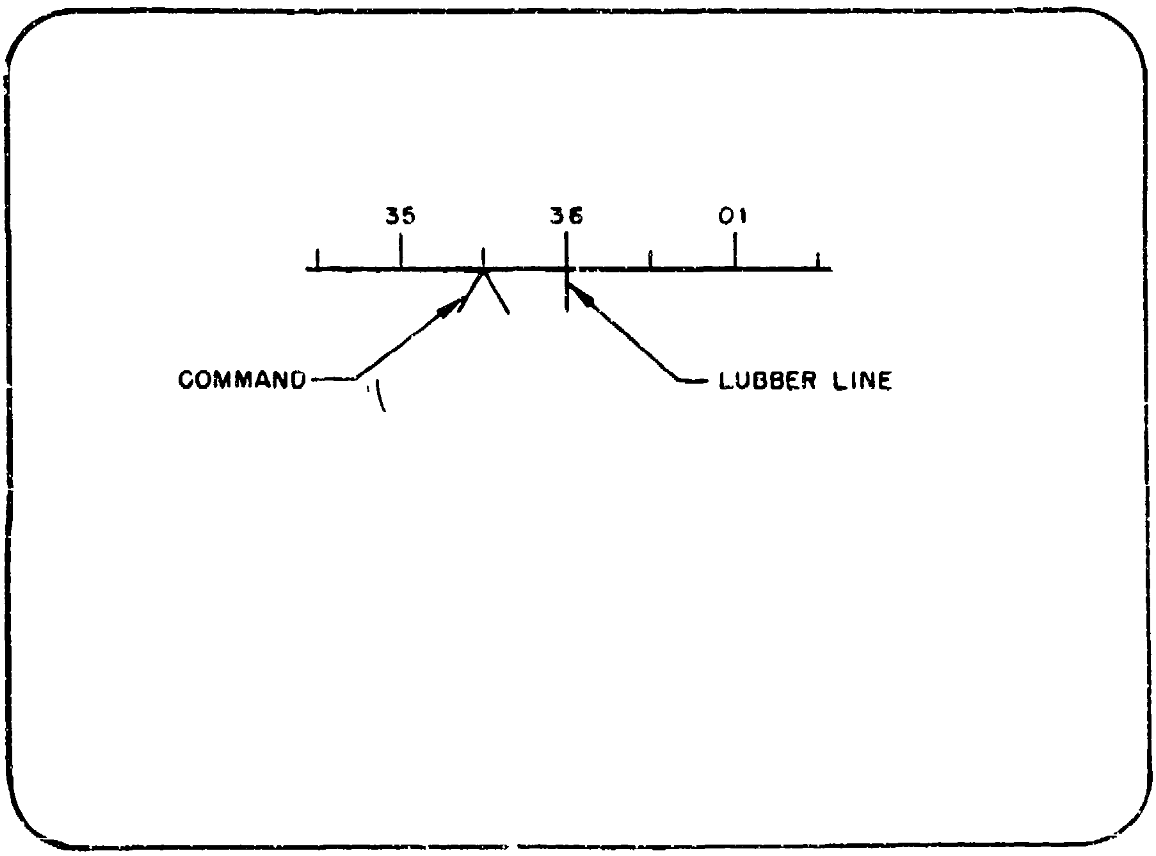


Figure E-6. Heading (from MIL-STD-884C, 1975).

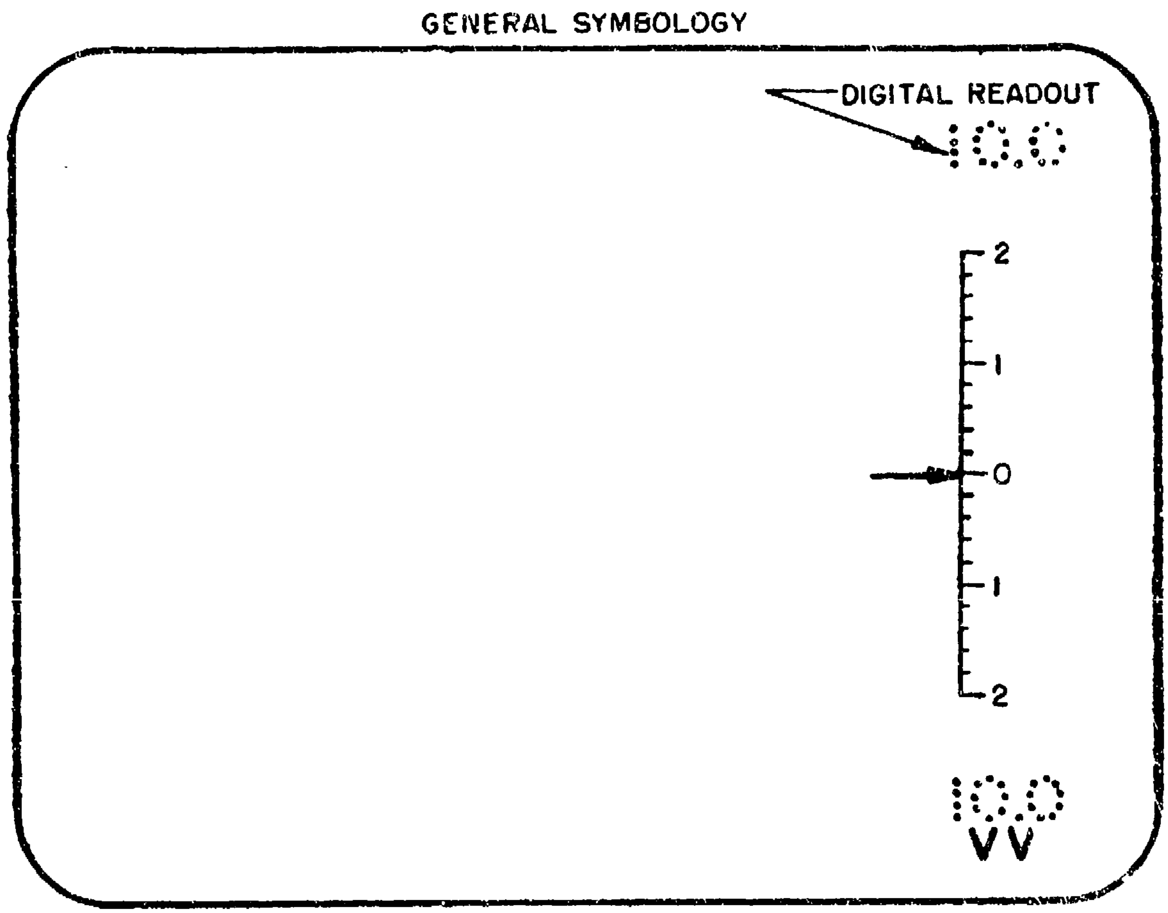


Figure E-7. Vertical Velocity (from MIL-STD-884C, 1975).

GENERAL SYMBOLOGY

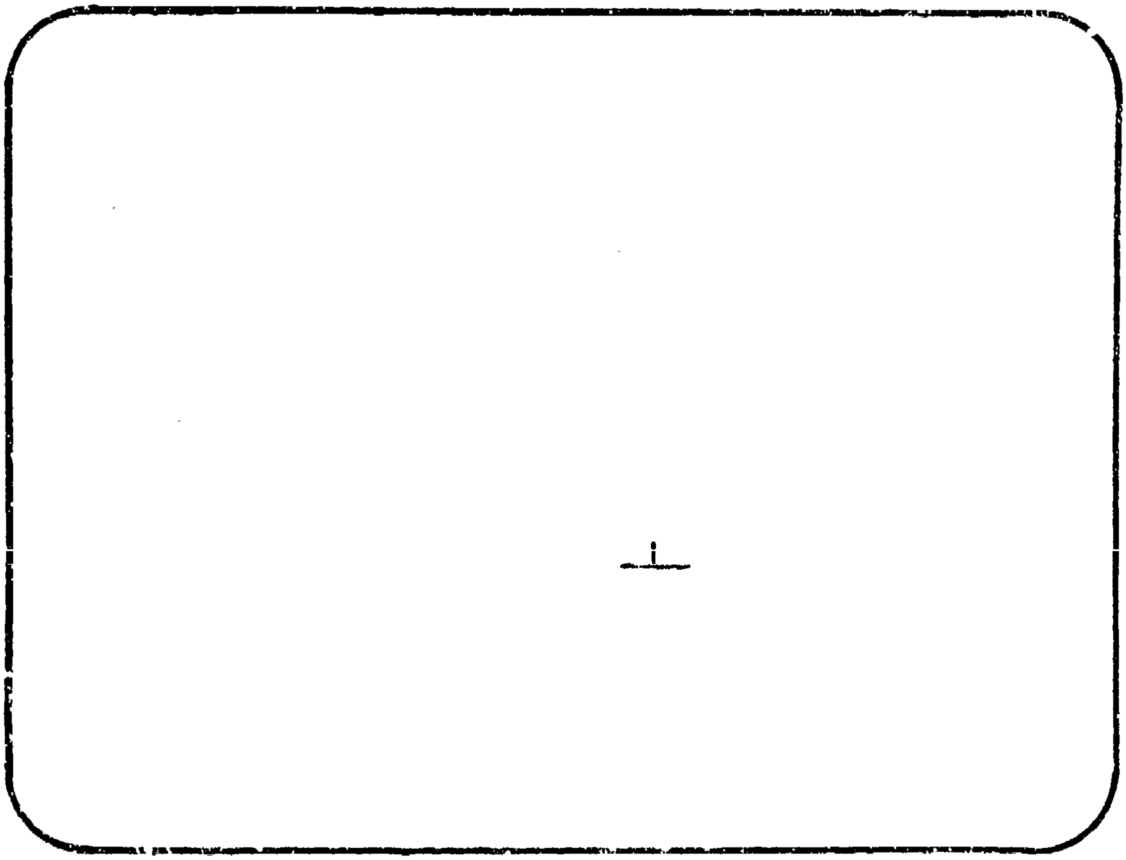


Figure E-8. Flight director information (from MIL-STD-884C, 1975).

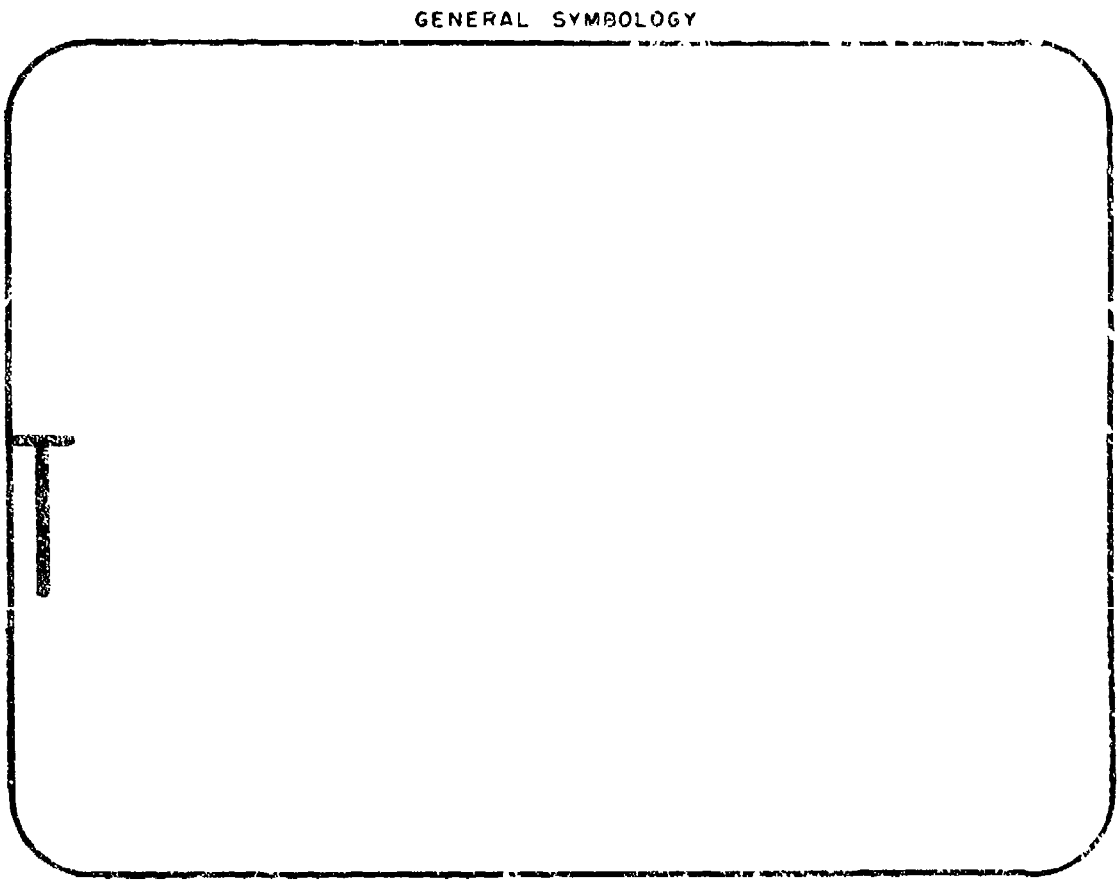


Figure E-9. Speed error (from MIL-STD-884C, 1975).

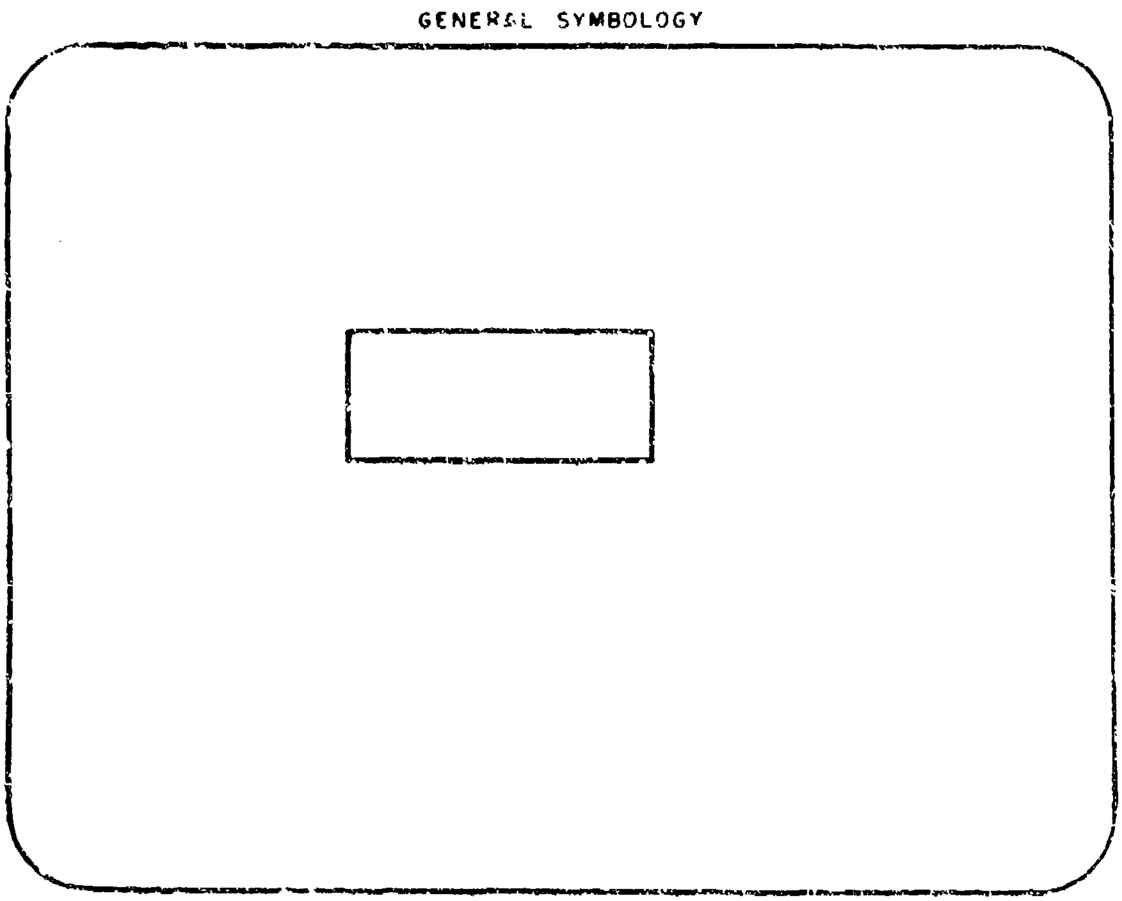


Figure E-10. Limits box (from MIL-STD-884C,1975).

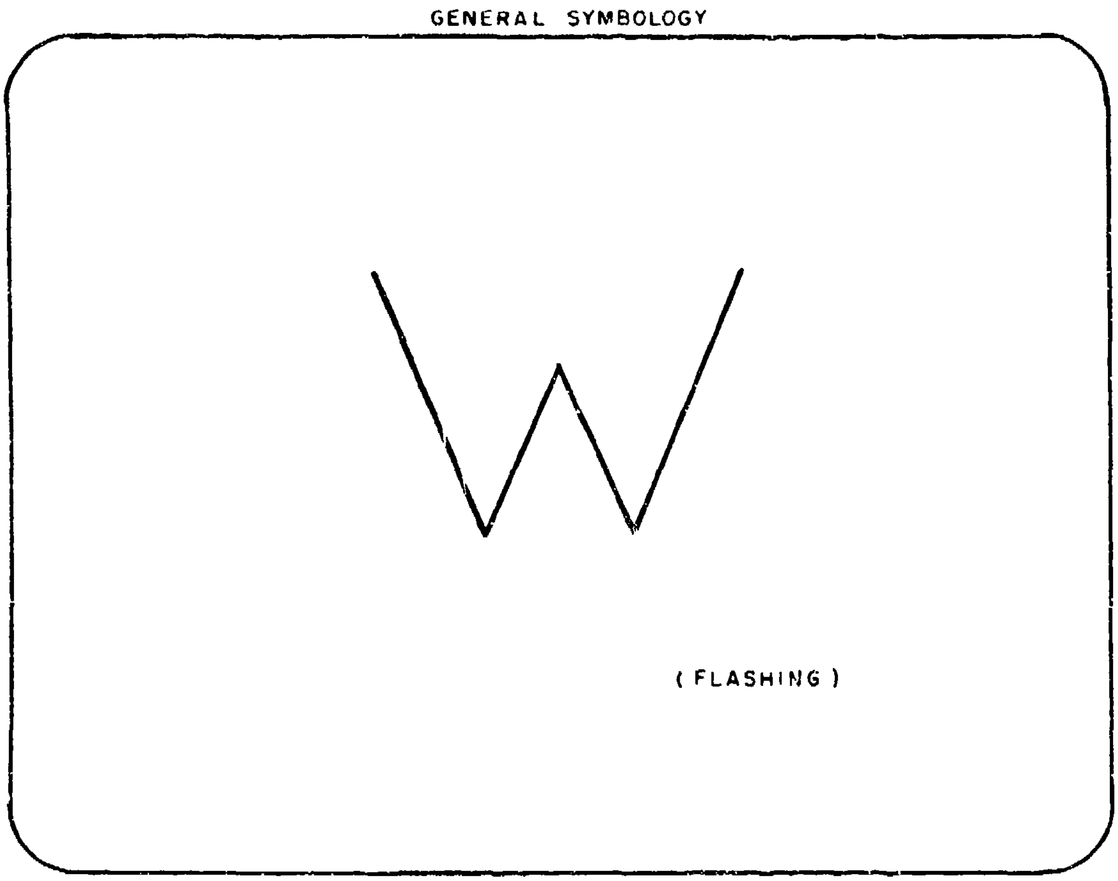


Figure E-11. Warning symbol (W or WARN) (from MIL-STD-884C, 1975).

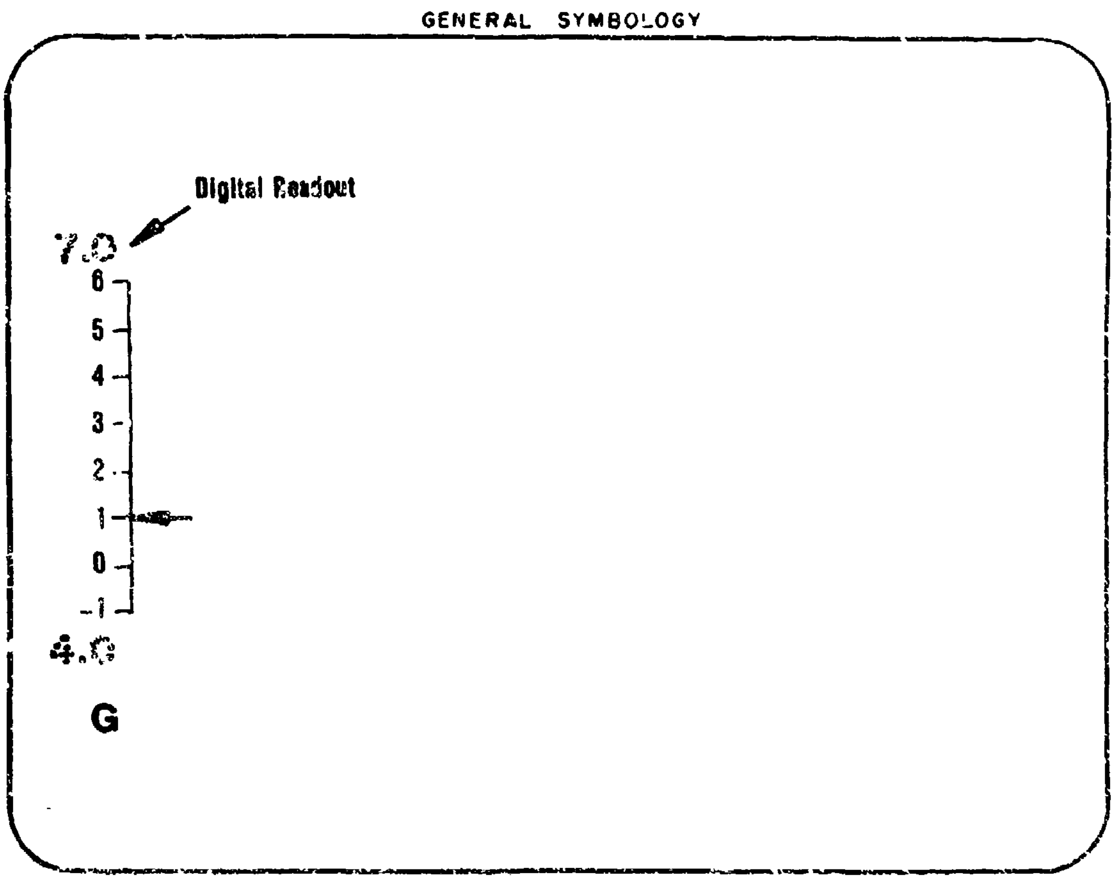


Figure E-12. Acceleration (g-forces).

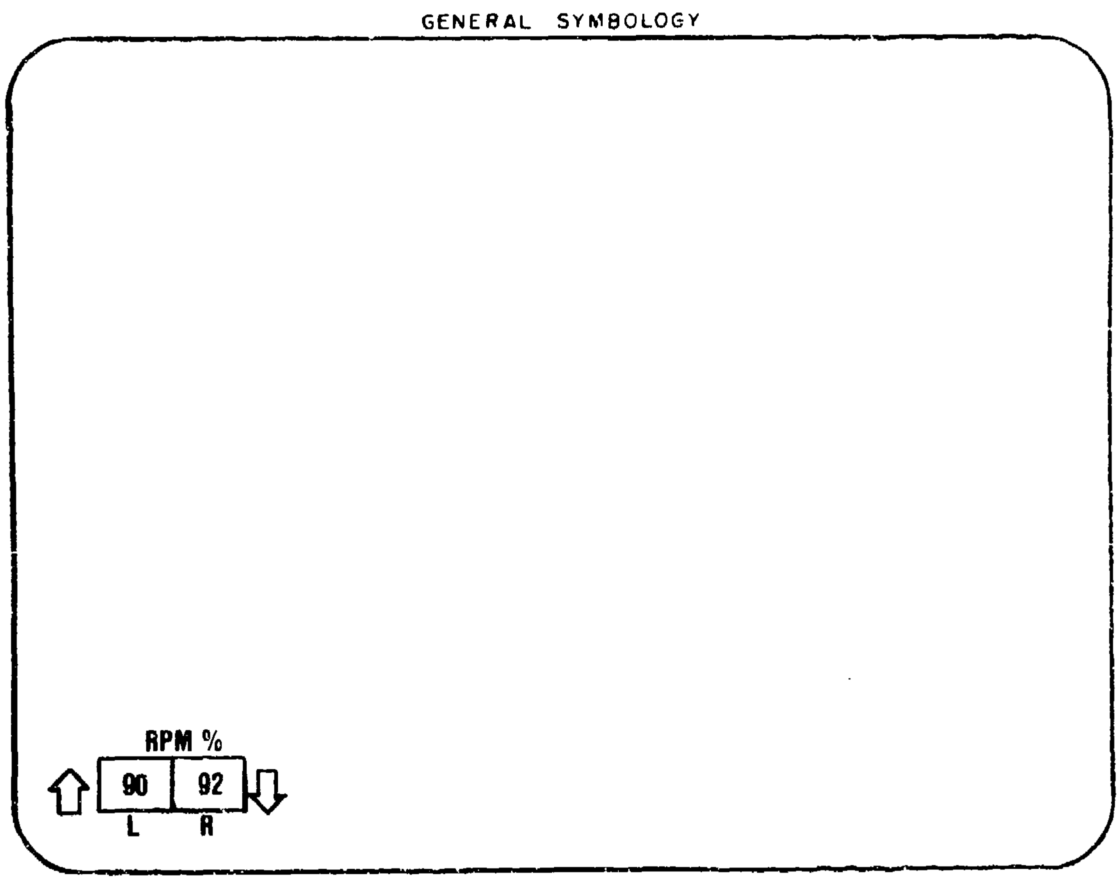


Figure E-13. Engine RPM.

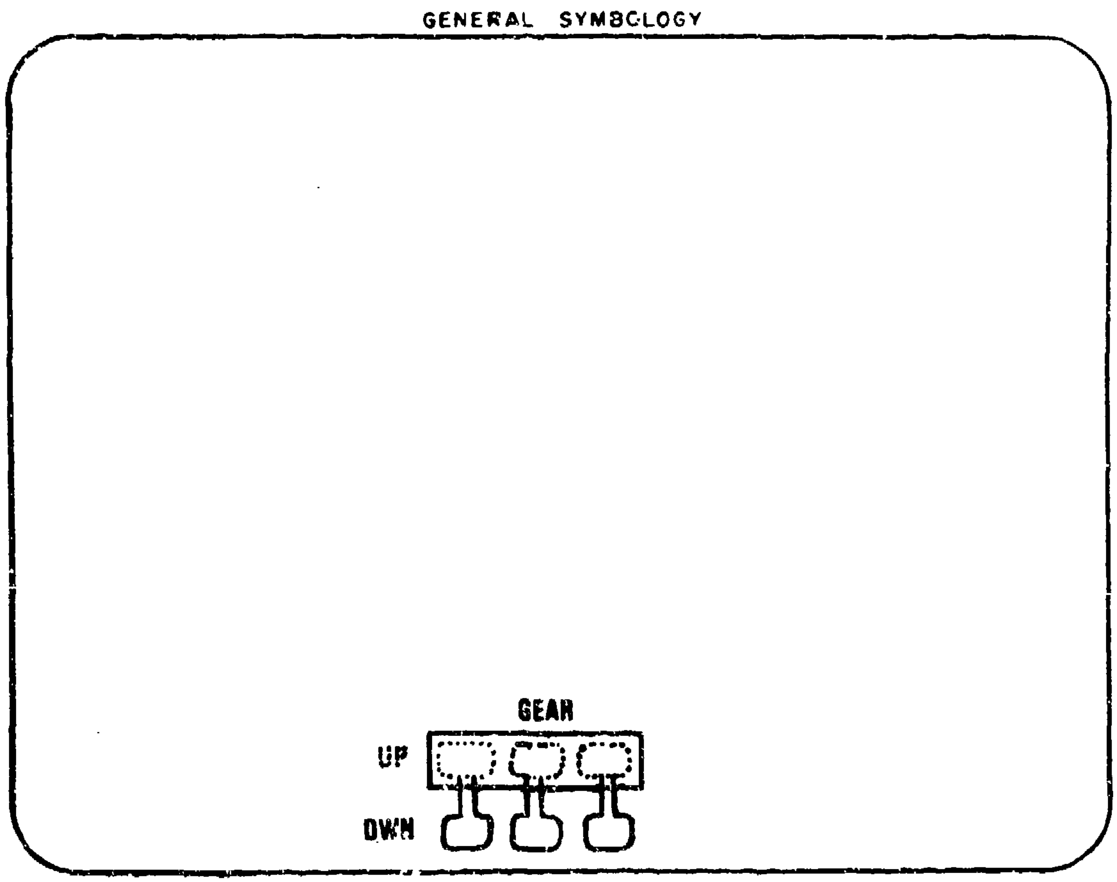


Figure E-14. Landing Gear.

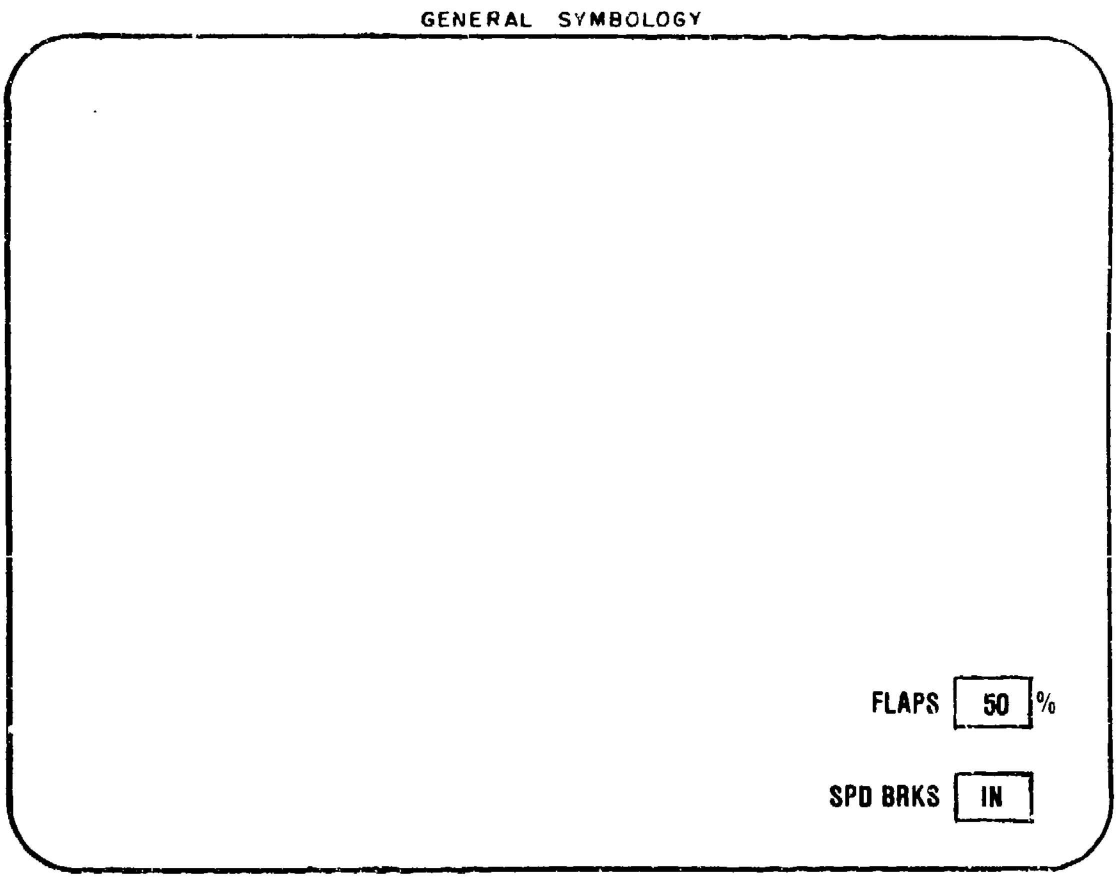


Figure E-15. Flaps and Speedbrakes.

GENERAL SYMBOLOGY

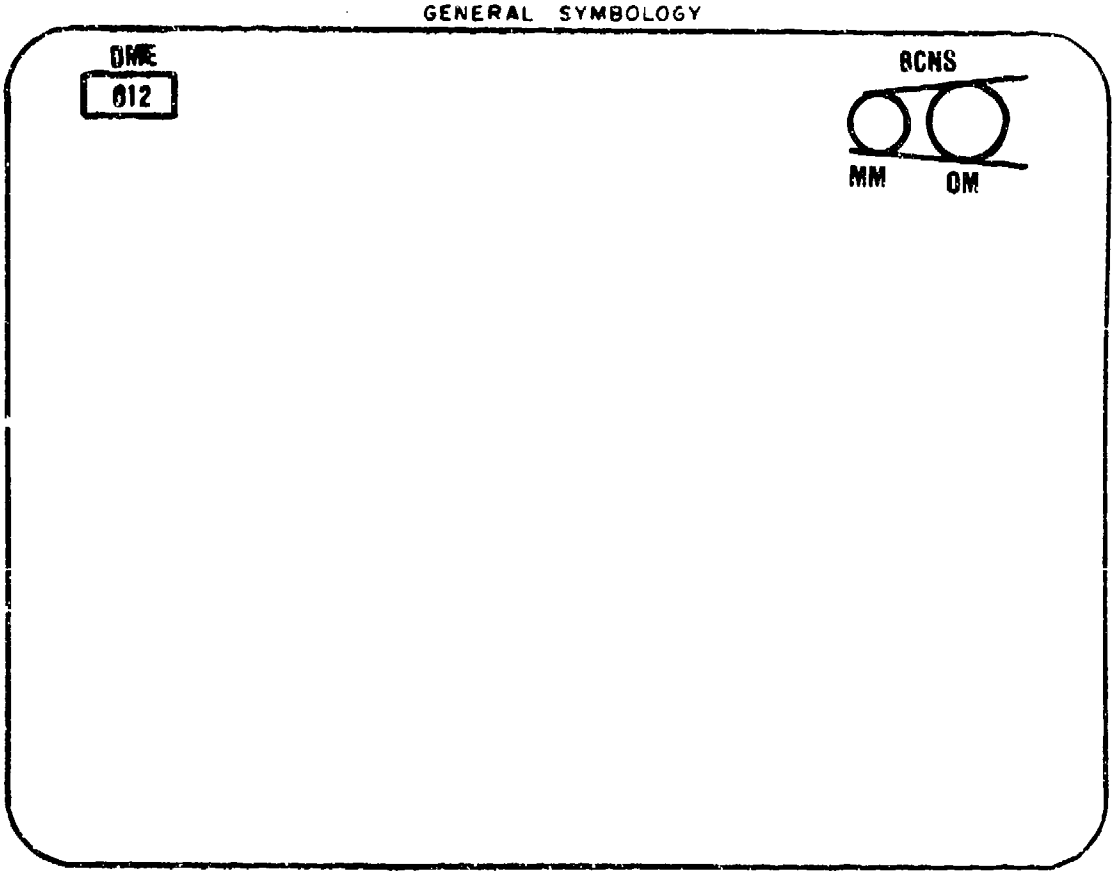


Figure E-16. DME and Marker Beacons.

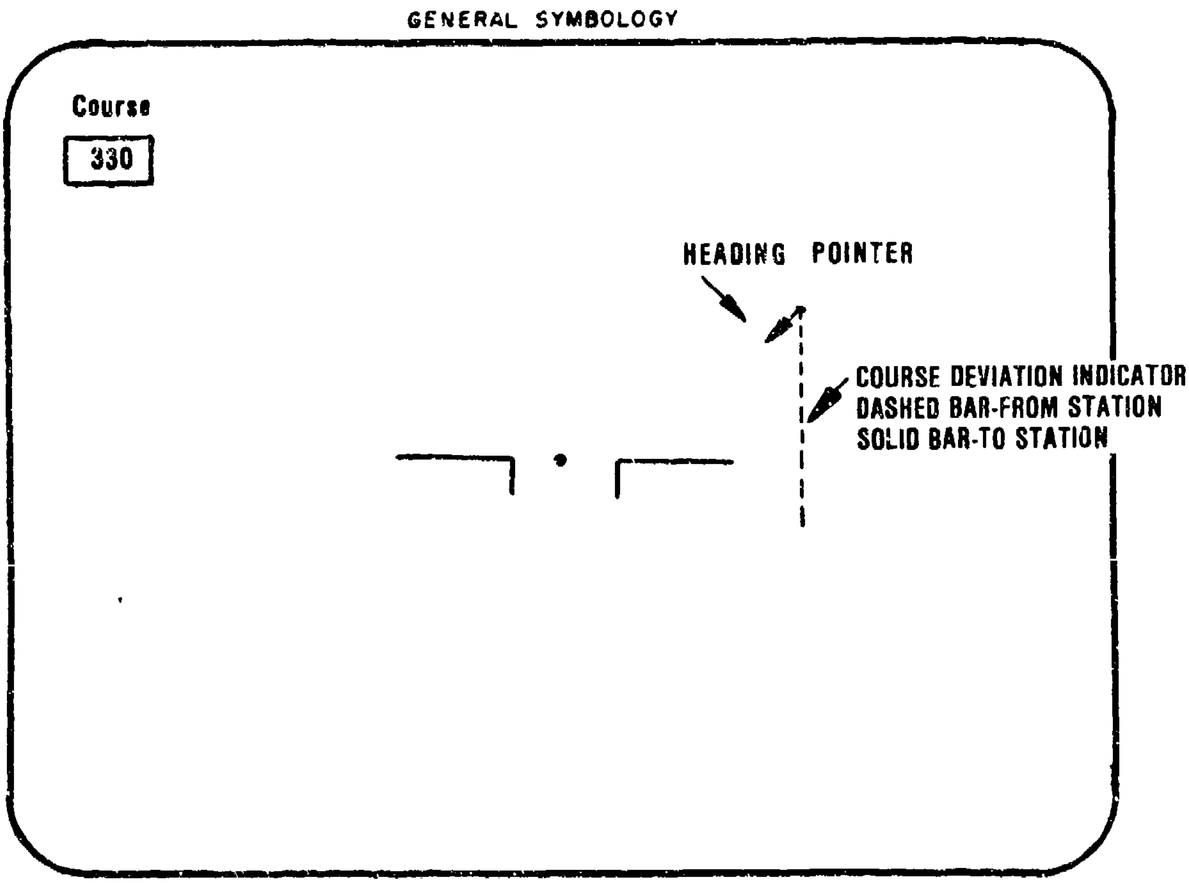


Figure E-17. Course Indicator.

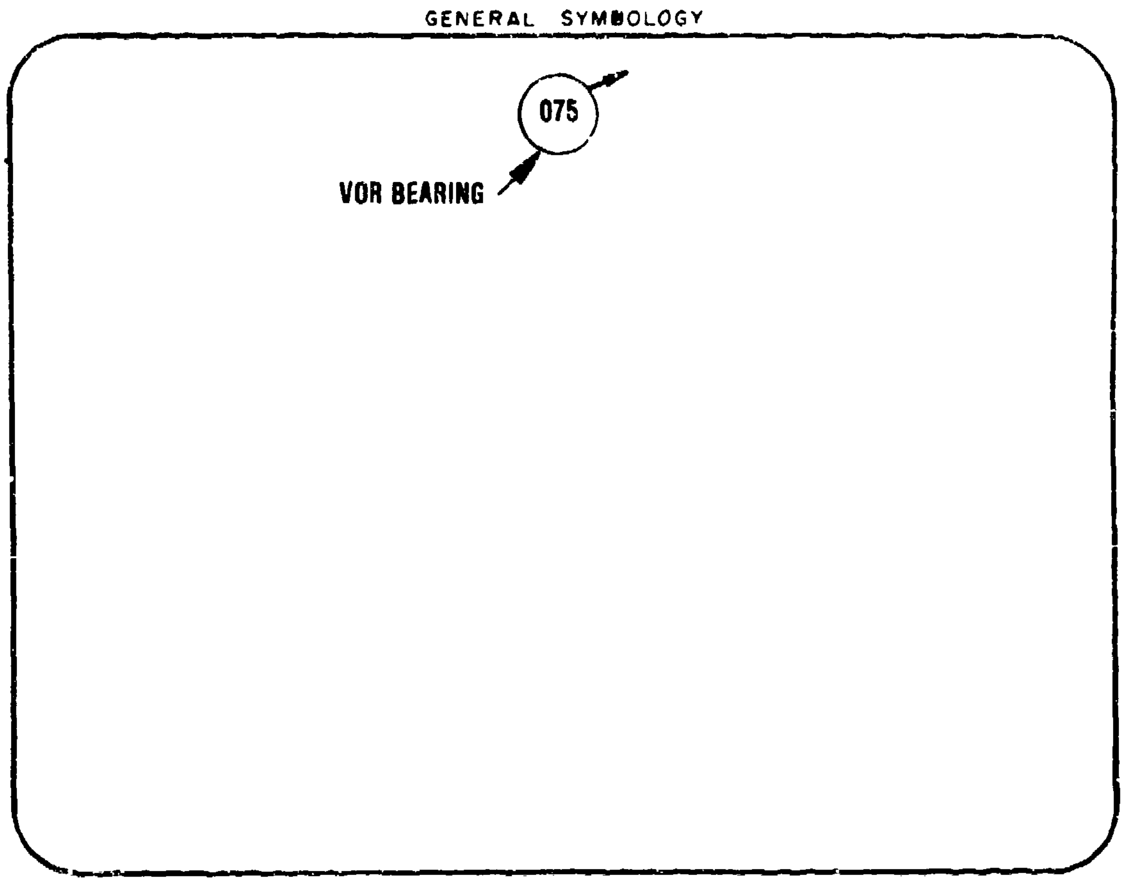
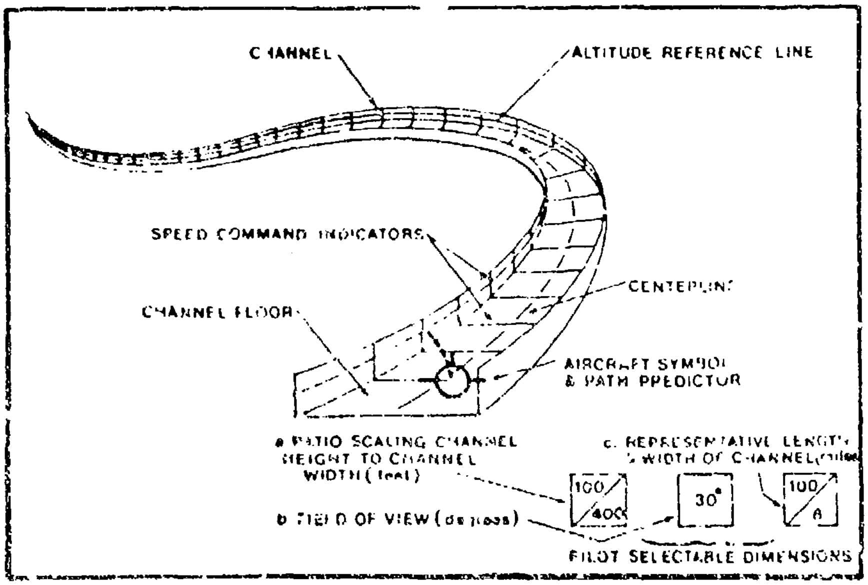


Figure E-18. Radio Magnetic Indicator (RMI).

A. Aircraft right of command path at command altitude; heading left



B. Aircraft above and left of command path; banking right.

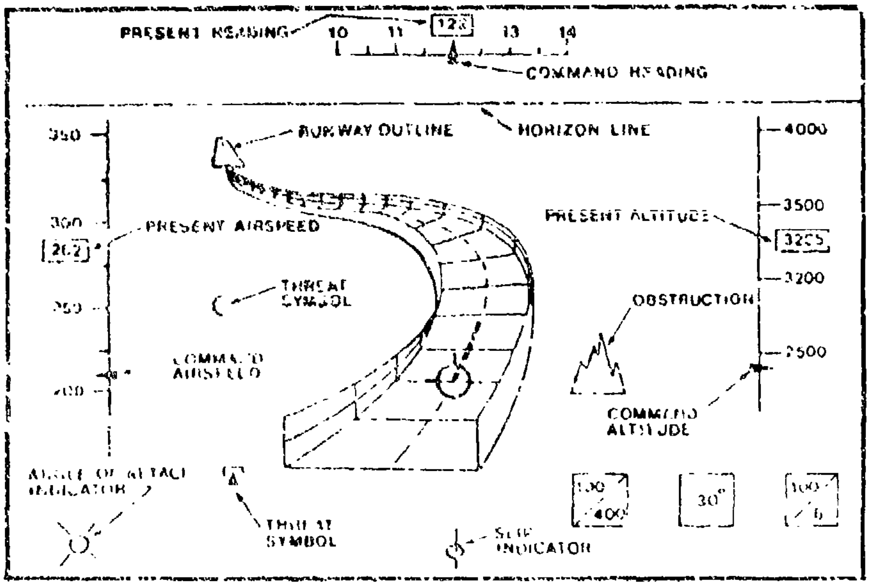


Figure 5-19. Proposed flight path display (from Warner, 1979).

APPENDIX F

Recommended Display Formats

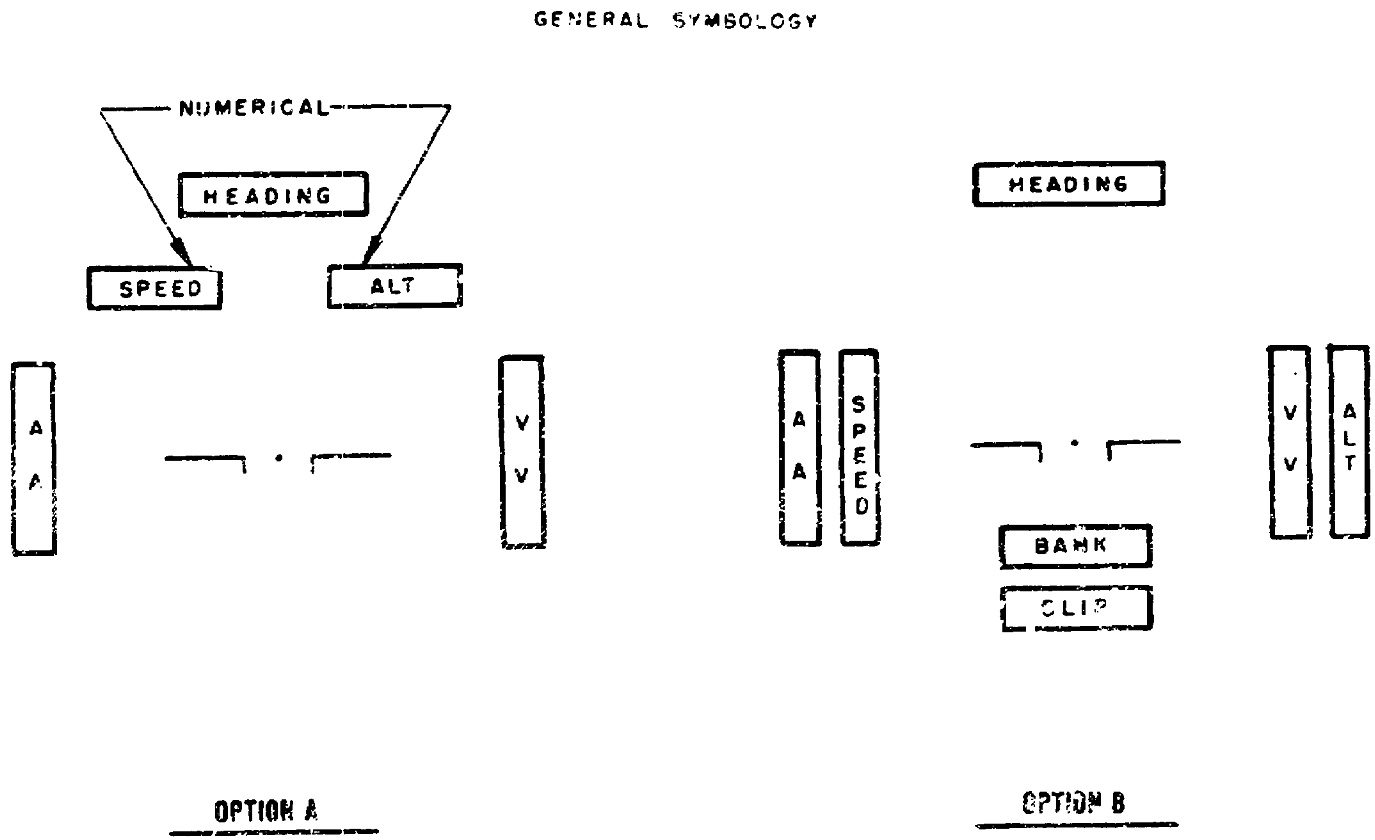


Figure F-1. Recommended display layouts (from MIL-STD-884C, 1975).